

ROCKET FUZES

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ROCKET FUZES

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ROCKET FUZES

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT
National Defense Research Committee, Division 3, Section L
OSRD Report No. 2545

This volume is presented as an item in the final technical report of OSRD Contract OEMsr-418, and is pertinent to all rocket projects assigned to the contract. The work reported was supervised by C. C. Lauritsen, Director of Research, and William A. Fowler, Assistant Director of Research. The contents have been approved for the National Defense Research Committee by B. M. Norton, Technical Aide, Section L, Division 3, NDRC, and for Contract OEMsr-418 by E. C. Watson, Official Investigator. Following is a complete list of the book-length reports prepared under OEMsr-418.

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ROCKET FUZES

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PREFACE

The material presented in this book is not an exhaustive treatise on fuzes or even on rocket fuzes but is essentially a description of the rocket fuzes developed by the California Institute of Technology (CIT) and a discussion of the problems involved in the work. Practically all of the fuzes were developed for use in CIT rockets and all are mechanical in operation.

The text is organized for convenience in presentation. Some of the chapters (for example, Ch. 2 and 3) describe series of fuzes of the same general type; individual fuzes in these series may have been intended for quite different rocket types. Other chapters (as Ch. 6 and 7) treat of a variety of fuze types designed for the same purpose or for rockets of the same class.

Many different fuzes are described, two factors having contributed to the large number developed:

1. A great number of different rockets were developed. The characteristics of these were often quite different, and their applications, which to a large extent determined the character of the fuzes to be used, varied still more widely. As a consequence it was seldom possible to use the same fuze in more than one or two rockets. Fortunately, in many cases only slight modifications of an existing design were necessary to adapt a fuze to a new rocket.

2. Different types of fuzes or improvements and modifications in a fuze for a given rocket were often required as information on the performance of the fuze was gained from tests and service use, or as a result of changed service requirements.

Many of the fuzes described in the following pages were never standardized for service use. This also arose from two principal causes: first, the rocket for which the fuze was developed was often not standardized; second, the fuze for a certain rocket sometimes proved inadequate and had to be replaced by a different design, or by a modification with a different designation, prior to standardization. It was usually considered that a fuze was standardized when a Navy Mark number was assigned to it by the Bureau of Ordnance, but sometimes this was assigned in early stages of the work, and subsequent events led in a few cases [notably the Mk 144 (NIR) fuze] to the fuze thus standardized being replaced by a different fuze prior to production for service use.

The treatment given in the following chapters is largely descriptive in character. In most cases, instead of giving actual test data, reference is made to published CIT reports containing such data, and only a general presentation of the development is given. In some cases, however, the data for which have not been previously published, a more complete history of the development work is included. The Introduction (Ch. 1) points out some of the general fundamental problems and requirements for rocket fuzes, and the introduction to each chapter deals more specifically with the problems and requirements associated with the type of fuze treated there.

An understanding of the reasons underlying the choice of the particular types of fuzes to be developed may be gained by a brief discussion of the attendant circumstances. The keynote was always expediency. Because of the constant demands

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for new fuzes and modifications it was not thought practicable to undertake any fundamental researches or long-range programs; for this reason the development activities were confined largely to working the "bugs" out of fundamentally simple devices. Thus the fuzes worked on were restricted to mechanical types, the general principles and requirements for which were well established in projectile and bomb fuzes. For the same reason no research on new or different explosive components was attempted. Whenever possible the explosive trains were either the same or similar to those used in standard bombs or gun projectiles.

Usually only a very short time was available to spend on a given fuze. Hence in many cases a fuze developed for a particular rocket was adapted, with the fewest possible modifications, for a new requirement. This procedure seldom resulted in obtaining an entirely satisfactory fuze, since the difference in the characteristics and applications of rockets is so marked. In projectile and bomb fuzes, on the other hand, these differences are relatively small, and minor modifications of fundamental designs often suffice.

The rocket fuze development activities at CIT included not only design and testing of experimental models but the preparation of Bureau of Ordnance drawings and specifications and the production and loading of many of the fuzes in quantity sufficient for large-scale service testing. The latter activity (pilot production), because of the urgency involved, was always initiated long before development could be said to be complete, and as a consequence changes in design were constantly being introduced, the necessities for which were indicated by the concurrent testing program. However, in order not to impede the production program unduly, it was often necessary to work out compromises and keep the number of changes to a minimum and their character relatively minor. As a consequence most of the fuzes described here have well-known shortcomings which have, because of the practical difficulties and complications involved, never been properly corrected. In short, if production had awaited completion of development and the elimination of all design and operational difficulties, few if any rocket fuzes would have been made available for service use. In the course of the rocket fuze pilot production program a total of more than 400,000 fuzes of some 15 varieties were manufactured and loaded for service test and use.

The addition of pilot production to the design and testing phases of the fuze development program had certain advantages. Foremost of these was the experience gained by those concerned in design with the manufacturing and material problems; thus, a factor of paramount importance—that a fuze be quickly and readily manufactured—was of necessity constantly kept foremost. The success of such a program was made possible only by the closest liaison between the CIT Fuze Group, the cognizant sections in the Naval Bureau of Ordnance and the Naval Ordnance Laboratory, and numerous manufacturing and loading plants under both CIT and Bureau of Ordnance contracts.

A word should be included to point out the importance of the relationship between the fuze and other components of a rocket. To a greater extent, perhaps, than any other component, the fuze is dependent on the characteristics of the other parts (motor and head) of the rocket, and conversely the whole rocket is dependent, for the ultimate fulfillment of its purpose, on the action of the fuze. In particular,

the arming phase of the fuze operation is usually closely dependent on the characteristics of the rocket motor (burning time, pressure, velocity, etc.). The firing or functional characteristics of the fuze are closely related to the character of the rocket head. Thus the characteristics, requirements, and applications of the rocket as a whole must be considered in fuze design. Of particular importance in determining the effectiveness of the rocket is the proper inter-design of fuze and head. Unfortunately in many important instances rocket heads used have been modifications of projectiles,¹ adopted to facilitate procurement, and considerations of the optimum "Terminal Ballistics" of the rocket were of necessity secondary. Rockets have certain peculiar characteristics, chief of which is the ability to remain stable and to penetrate a great distance in ground or water. To take advantage of potentialities such as this the closest correlation between fuze and head design is required, and its importance cannot be overemphasized.

The fuze activities discussed above were carried on as part of OSRD Contract OEMsr-418 under C. C. Lauritsen, Director of Research, and W. A. Fowler, Assistant Director of Research. The Fuze Group research staff was composed of R. B. King, Group Supervisor, D. E. Brink, H. E. Fracker, Norman Gunderson, J. B. Hatcher, D. L. Kraus, R. E. Martin, J. W. Petty, and V. K. Rasmussen. The fuze drafting group, who produced drawings for CIT development and pilot production purposes, and also prepared Bureau of Ordnance drawings for a number of fuzes standardized by the Navy, was under the supervision of W. F. Sapp of the Bureau of Ordnance Design Unit. Fuze shop activities, including outside subcontracting of experimental work and pilot production and loading of fuzes for CIT and the armed services, were under the supervision of S. A. Macallister with the cooperation of Mr. Petty and other members of the research group.

The present volume on Rocket Fuzes was written by four members of the Fuze Group staff. The Preface and Chapters 1, 2, and 3, except Sections 2.09 and 2.10, were written by R. B. King; Sections 2.09 and 2.10 and Chapters 4 and 5 were written by V. K. Rasmussen; Chapter 6 was written by J. B. Hatcher, and Chapter 7 by H. E. Fracker.

¹ In the 5.0-in. AR and 5.0-in. HVAR, for example, the most widely used head was a modification of the 5.0-in. Mk 35 AA projectile. That of the 11.75-in. AR was a modified 500-lb SAP bomb casing.

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Chapter 1

INTRODUCTION

1.00. GENERAL.—Rocket fuzes, like those for bombs and projectiles, are devices containing explosives. They have two prime functions: (1) to detonate (or in some cases ignite) the charge in the rocket head under the proper circumstances, and (2) to protect the assembled rocket from premature detonation by the fuze under all conceivable circumstances.

It is because these two requirements (for functioning and safety) are not easily made compatible that fuzes appear at first glance to be unnecessarily complicated mechanisms. Actually this is not often true, since every effort is made in fuze design to make the mechanism as simple as possible; this is done in order to facilitate immediate quantity procurement and to avoid as many as possible of the "bugs" which inevitably crop up in the later stages of development and often after the fuze is in service use. Indeed, the constant demand for simplicity in design and for ease in manufacture is responsible for many of the fundamental shortcomings in the design of rocket fuzes as well as others.

Because the two basic fuze requirements mentioned above are separate and distinct, a fuze mechanism can usually be thought of functionally as two sets of interrelated mechanisms: one, the arming mechanism, concerned in rendering the fuze safe and in operating only under the proper circumstances to permit the other, a firing mechanism, to function. Usually a number of the fuze parts are involved in both processes.

1.01. CLASSES OF ROCKET FUZES.—In general, rocket fuzes closely parallel gun projectile fuzes in type and operation, because rockets are used for the same general purposes as gun projectiles, and the only fundamental difference between the two is in the methods used in propelling them. Thus, the general classes of fuzes used in projectiles¹ are also found in rockets:

1. *Nose fuzes*, including:
 - a. Point-detonating fuzes, designed to fire instantaneously on impact.
 - b. Time fuzes, designed to burst the rocket head at some predetermined time after the rocket is launched.
2. *Base fuzes*, installed in the base of the rocket head, designed to detonate with delay on impact.
3. *Auxiliary detonating fuzes*, or *boosters*, used in conjunction with some nose fuzes (in spin-stabilized rockets only), primarily to provide additional safety.

Rocket fuzes may be also classified in a different manner according to the type of rocket in which they are used:

1. *Fuzes for fin-stabilized (nonrotating) rockets*, including both nose and base fuzes. The majority of fuzes developed specifically for rockets fall in this category, for reasons explained in the following section. Fin-stabilized rockets themselves

¹ BuOrd Publication Ordnance Pamphlet 1212, 23 May 1945.

may be roughly divided into two classes, (a) those launched from aircraft, and (b) those launched from ground or shipboard, and the fuzes for these two types may have different requirements.

2. *Fuzes for spin-stabilized (rotating) rockets*, also including both nose and base fuzes, and auxiliary detonating fuzes in addition. Because the spin of these rockets is of the same order of magnitude as that of gun projectiles, and because spin is utilized in arming many projectile fuzes, in most cases projectile fuzes can be adapted for use in rotating rockets with little or no modification. It is only when a fuze for spin-stabilized rockets must meet special functional requirements, for which there exists no applicable projectile fuze, that a completely new design is necessary.¹

3. *Fuzes for antisubmarine rockets (ASR)*. The operation of these fuzes, with the exception of the Mk 139 (SIR), depends almost entirely on conditions existing after the round strikes the water, the fact that the projectiles are rocket-propelled playing a very small role.

1.02. FORCES USED IN ARMING ROCKET FUZES.—The forces that act on the rocket when it is fired are utilized, as in projectile and bomb fuzes, to arm rocket fuzes. Since these forces are different in varying degrees, depending on the rocket, from those which act on projectiles and bombs, special fuzes have been of necessity developed for rocket use.

The requirements for safety in fuzes may be generalized as follows: a fuze should be so designed that it cannot function (except by deliberate tampering) unless the round in which it is assembled is actually fired or launched under normal conditions. This is a difficult requirement to satisfy in rocket fuzes and has not by any means been met in many of the present designs. It does, however, determine that the forces which must be utilized to arm fuzes are those which occur when the rocket is fired. Unfortunately most of these forces are not large, and usually it is necessary to utilize a combination of them with the idea that the chances of their simultaneous occurrence under any other circumstances than the actual launching of a rocket would be negligible.

The principal forces used in arming gun projectile fuzes² are those due to acceleration (setback forces) of the projectile in the bore of the gun, and centrifugal force due to spin. The principal force utilized in bomb fuzes is that exerted by the wind stream as the bomb falls through the air. These forces are also present in rockets but in different degrees. Thus, the forces which have been utilized in rocket fuzes have depended on the characteristics of the rocket for which the fuze is designed. Since there has been an unusually wide variation in these characteristics in different rockets, it has been necessary to utilize different forces in different fuzes.

The forces acting on rockets which must be considered and may be utilized in fuze design are listed below.

1.021. ACCELERATION (SETBACK).—Low acceleration and long burning time during which the rocket accelerates are characteristic of rockets. The acceleration

¹ For example, the CCISR fuze, Section 6.42.

² BuOrd Publication OP 1212, p. 6.

of most CIT¹ rockets is fairly constant during the burning time, although in some there is a marked decrease as burning progresses.² The values of acceleration of different rockets vary over a fairly wide range, and the acceleration of a given rocket, as well as the burning time and distance, is strongly dependent on the temperature of the propellant of the rocket motor (see Table 1). Thus, any mechanism actuated by setback forces must be adjusted to operate at the minimum acceleration of the rocket in which the fuze is used (allowing a safe margin for frictional forces). In guns, since acceleration of the projectile is very large, being about 14,000 g in 5-in. naval guns, for example, setback can readily be utilized either as a primary arming force or as a force to prevent arming until the projectile has left the muzzle (which is required for bore safety). As can be seen from the values given in Table 1 the acceleration of some rockets may be extremely small, sometimes so small as to be of doubtful use. Because of this, setback cannot be safely used as a primary arming force in rockets, but can be used only in conjunction with other forces, as in AIR and PIR fuzes. As in projectile fuzes, setback is often utilized in rocket fuzes as a means of delaying arming until the round is a safe distance from the launcher,³ which is usually considered to be the burning distance. The smallness of the setback forces available requires that the parts operated by setback be relatively massive and the springs relatively weak as compared with those in projectile fuzes.

1.022. WIND FORCES.—The force exerted by the wind stream past the rocket in flight is utilized to arm many rocket nose fuzes (the AIR group) for fin-stabilized rockets. The static air pressure at the nose of the rocket also has been utilized in the NIR fuze for high-velocity rockets, for which its magnitude is appreciable.

1.023. PRESSURE OF PROPELLANT-CHARGE GAS.—During the burning of the rocket motor, pressure of the propellant gas is exerted on the base of the rocket head. This pressure, of the order of several hundred pounds per square inch, lasts for an appreciable time (see Table 1) in CIT rockets, and is also fairly constant during the burning time. It has been utilized to arm the PIR and DDR base fuzes. Because the pressure lasts for a considerable time, its entrance into the fuze can be delayed so that arming does not take place until the rocket is well clear of the launcher. The magnitude of the gas pressure and the time during which it is exerted (burning time) vary with the type of rocket and are also strongly dependent on temperature (Table 1).

1.024. TEMPERATURE OF PROPELLANT GASES.—The burning of the propellant makes heat available which can be utilized to arm base fuzes. This energy has not been utilized as a means of arming in CIT rocket fuzes, but has been used in certain British fuzes in conjunction with gas pressure, to obtain an arming delay. It is also available as a means of initiating powder trains in ejector fuzes.

1.025. CENTRIFUGAL FORCE.—This continuous force, due to spin, is present only in the spin-stabilized rockets. It increases steadily to a maximum at the end of

¹ Throughout this book the abbreviation *CIT* will be used for the *California Institute of Technology*.

² The burning in such rocket motors is said to be "regressive."

³ The AIR-8 and the PIR fuzes are examples of this use of setback.

TABLE

BUORD DESIGNATION	CIT OR FORMER BUORD DESIGNATION	MOTOR	HEAD	NOM. VEL. (ft/sec)
7.2" Rocket Mk 1 Mod 0	7.2" Rocket Mk 6 (antisubmarine)	2.25" Mk 3	7.2" Mk 4	165
7.2" Rocket Mk 1 Mod 2	7.2" DR Model 17	2.25" Mk 3	7.2" Mk 10	155
—	7.2" DR Model 18 (fast-burning)	2.25" Mdl 14	7.2" Mk 10	160
—	7.2" DR Model 19 (100-ft range)	2.25" Mdl 15	7.2" Mk 10	60
7.2" Rocket Mk 7 Mod 0	7.2" Rocket Mk 11 (retro: 200 ft/sec)	3.25" Mk 1	7.2" Mk 6	210
7.2" Rocket Mk 10 Mod 0	7.2" Rocket Mk 12 (retro: 300 ft/sec)	3.25" Mk 2	7.2" Mk 6	310
7.2" Rocket Mk 12 Mod 0	7.2" Rocket Mk 13 (retro: 400 ft/sec)	3.25" Mk 3	7.2" Mk 6	400
4.5" Rocket Mk 1 Mod 0	4.5" BR Mk 2 (standard)	2.25" Mk 8	4.5" Mk 2	355
—	4.5" BR (250 yd)	2.25" Mk 8	4.5" Mk 4	150
—	4.5" BR (1000 yd)	2.25" Mdl 7	4.5" Mk 2	335
3.5" Rocket Mk 1 Mod 1	3.5" AR Model 12	3.25" Mk 7	3.5" Mk 3, 5	1090
5.0" Rocket Mk 1 Mod 1	5.0" AR Model 11	3.25" Mk 7	5.0" Mk 1	700
5.0" Rocket Mk 4 Mod 0	5.0" HVAR Model 14A	5.0" Mk 1 or Mk 2	5.0" Mk 5 Mod 0, 1 or Mk 6 Mod 0, 1	1360
—	11.75" AR Model 4	11.75" Mk 1 Mod 2, 3	11.75" Mk 1 Mod 0 or 1 or Mk 2-0	830
—	7.2" CWR Model 15	3.25" Mk 5	7.2" Mk 7	680
—	4.5" Army Rocket T22	—	—	—

BURNING TIME			ACCELERATION			MAX. FRONT PRESSURE			MAX. CREEP FORCE
(sec)			(g)			(lb/in. ²)			(g)
0°F	70°F	120°F	0°F	70°F	120°F	0°F	70°F	120°F	
0.74	0.40	0.24	7	13	22	900	1450	150	—
0.70	0.36	0.23	8	14	22	900	1450	2200	—
0.30	0.18	0.10	18	30	48	1450	2450	3480	—
0.40	0.27	0.20	6	9	13	1100	1650	2700	—
0.56	0.34	0.22	11	20	31	850	1450	2150	—
0.62	0.37	0.25	15	26	38	70	1300	2200	—
0.64	0.38	0.23	19	33	49	700	1150	2100	—
0.66	0.37	0.22	16	30	50	850	1450	2150	—
0.47	0.23	0.18	—	20	26	1000	1800	2650	—
0.42	0.21	0.12	25	49	79	850	1650	2750	0.18
1.56	0.99	0.69	24	36	60	600	800	1200	6.7
1.61	0.99	0.69	15	25	30	600	800	1200	2.0
1.43	1.00	0.73	34	52	71	1200	1850	2600	4.6
1.33	1.04	0.72	22	32	42	1200	1580	2350	0.93
0.90	0.53	0.32	23	40	64	700	1300	2200	0.60
0.25	0.14	0.09	—	—	—	—	—	—	—

burning of the rocket and then decreases gradually along the trajectory because of air friction (see Chapter 6). The magnitude of the centrifugal force (which varies for different rockets) is of the same order as that in projectiles¹ and can be utilized in the same manner as in projectile fuzes.

1.026. CREEP.—This is the continuous inertia force caused by air drag, which tends to move internal fuze parts toward the nose of the round. Since it is dependent on the velocity of the rocket (Table 1), being greatest when velocity is greatest, it is at a maximum immediately after the end of burning of the rocket. It must be taken into account in fuze design, not only as a creator of frictional forces, but also as a force which tends to move parts forward and may require compensation by anticreep springs.

1.027. FRICTION.—Frictional forces due to setback and creep are not high in rockets. However, they must be considered in their effect on moving parts. In spin-stabilized rockets, friction due to centrifugal force may be quite large.

Other forces, which have little or nothing to do with the rocket itself, are used in arming ASR and Hedgehog fuzes (Chapter 7).

1.03. FIRING OF ROCKET FUZES.—Most rocket fuzes are fired by impact in the same general manner as gun projectile and bomb fuzes. The sudden inertia force of impact makes all movable parts in a fuze move forward when the round strikes an object, and may be utilized to drive a firing pin into a primer, as in PIR fuzes, or to unlock a spring-loaded firing pin, as in HIR fuzes, for example. In point-detonating nose fuzes impact with an object may drive a movable striker back into the detonator. Impact problems are discussed further in later chapters.

1.04. EXPLOSIVES USED IN FUZES.—The explosive materials used in rocket fuzes are the same as those used in bomb and projectile fuzes and are subject to the same requirements and composed of the same materials.²

The explosive train in a rocket fuze usually consists of the following components:

1. The *primer*, which is initiated mechanically by the firing pin. Two types are used, (a) the stab type, initiated by the penetration of a sharp-pointed firing pin into the metal case and the primer mixture, and (b) the percussion type, initiated by crushing the primer mixture between a round-pointed firing pin and a flat metal anvil. Primer mixtures are intended to produce flame and hot gases and particles as a result of mechanical disturbance, and are generally composed of an initiating explosive (as lead azide), an oxidizing agent (as potassium chlorate), and a reducible substance (as antimony sulfide), and may contain a friction-creating material (as fine carborundum crystals). Lead azide primer mixture is usually used for stab-type primers because of its slower rate of decomposition, especially at higher temperatures. Mercury fulminate primer mixture is almost always used in percussion primers because of its greater sensitivity. The sensitivities of both types of primer are dependent on the shape and dimensions of the firing pin used, and on the velocity and energy with which it strikes. The stab-type primer is generally much more sensitive than the percussion type.

2. The *delay element*, a compressed pellet of black powder which is ignited

¹ Compare Table 1, Chapter 6, with table on p. 7 of OP 1212.

² See OP 1212, p. 7.

by the primer. It will burn uniformly and consistently only under considerable pressure, so that a percussion primer, which can be initiated without perforating its container, must be used (see 2.09 for further discussion). The delay time obtained is varied by adjusting the composition of the black powder, the pellet pressure, and the thickness of the wall that must be burned through. Only certain fuzes, which are classed as delay fuzes, will contain a delay element.

3. The *detonator*, which is initiated by the flash from the primer or delay element. It is composed of a pure initiating explosive, usually lead azide, which may be followed by a small amount of tetryl.

Because of their sensitivity, the above three components are necessarily loaded and sealed into small metal containers that are independent of the fuze in which they are used. They may all be in the same container, in which case the whole assembly is loosely referred to as the detonator. It is these components of the explosive train which are out of line with the remainder of the explosive train in the unarmed fuze and in line in the armed fuze to effect detonator safety.

4. The *lead-out* and *lead-in*, which are small pellets of tetryl used to reinforce the small detonation of the detonator and to transmit it to the booster. A lead-out is not necessarily used; if used, it usually moves with the detonator during arming.

5. The *booster*, a comparatively large tetryl pellet which is initiated by the lead-in and in turn initiates the main high-explosive filler of the head, either directly or through an auxiliary booster of granulated TNT. In cases where the main filler of the head is not high explosive, but chemicals, etc. which are to be scattered, the lead-in fires directly into a burster which may be either tetryl or black powder, depending on the violence and the type of scattering desired.

No new explosive materials have been developed for rocket fuzes. In most cases detonators designed for gun projectile or bomb fuzes have been used. The principal detonator developed specifically for a rocket fuze is the 0.020-sec delay detonator, developed by the Naval Ordnance Laboratory for the Nose Fuze Mk 145, and subsequently used in other rocket fuzes.

1.05. GENERAL SAFETY REQUIREMENTS.—The safety requirements for rocket fuzes are in general similar to those for gun projectile fuzes.¹ The fuze must contain adequate safety features to prevent detonation from any cause during transportation, handling, assembly, loading, and launching of the rocket. Rocket fuzes, like all other Navy fuzes, must be “detonator-safe”—that is, should the detonator be set off for any reason while the fuze is in the unarmed condition, the booster of the fuze (and hence the explosive filler of the rocket head) must not be detonated. This is accomplished by mechanically separating the explosive train between the detonator and the booster. The arming process in a fuze consists essentially in the alignment of these components. If it were not for the requirement of detonator safety, fuze mechanisms would often be much simpler than they are.

It is desirable that a fuze have at least two independent safety features to prevent functioning before or during firing or while in flight. Thus, the arming of the AIR fuzes (Chapter 2), for example, requires a combination of wind and sustained setback forces acting simultaneously. Such a combination may occur in other ways

¹ See OP 1212.

than by firing a rocket, but the probability is small. In nose fuzes a safety locking wire, removed only when the fuze is readied for use, is used to lock parts in the *unarmed* position.

Safety requirements peculiar to rocket fuzes were derived from the character and the manner of handling of rockets. For example, the aircraft rockets are assembled and loaded onto airplane launchers on board aircraft carriers, under which circumstances the possibility of premature launching of a rocket (accidentally or by fire) is not remote; it was therefore desired that the fuzes used in these rockets should not arm until the rockets had traveled at least 400 ft in flight (to clear the ship) and should not function if impact were sustained within this distance. Another characteristic of rockets is that occasional motor failure (blowup) may occur during burning of the propellant. This in itself is not usually serious but if the failure should occur when the rocket is on or just off the launcher the round would travel only a short distance, and, should the fuze be armed, might detonate on impact. Thus a requirement for all rocket fuzes is that arming of the fuze shall not be permitted until the rocket is well clear of the launcher.

Acceptance tests (see 1.08) of production lots of fuzes include certain standard tests for safety to insure that the safety features are effective.

1.06. GENERAL REQUIREMENTS FOR ROCKET BASE FUZES.—Base fuzes are called for when delayed detonation after impact is required. The basic requirements for the rocket base fuzes are in many respects the same as for gun projectile base fuzes, but new requirements peculiar to rocket fuzes were introduced; these may be summarized as follows:

1. *Functional*, to give delayed detonation of the rocket head after impact with the target. Thus, depending upon the type of head, the rocket, and the tactical use, the fuze must be:

- a. Sensitive enough to function on the lightest type of impact for which detonation of the rocket is desired.

- b. Strong enough to withstand the heaviest impact the rocket head itself is capable of withstanding, and yet give delayed, high-order detonation of the head.

Neither of these objectives is easily achieved. Base fuzes are generally fired by inertia forces resulting from impact. Since penetration of light plate, for example, may offer little resistance to the round, the velocity gained by the moving parts concerned with firing may be too small to fire the primer. For this reason a sensitive stab-type primer is often used, which results in greater sensitivity than that obtained when the percussion primer of a delay detonator is fired directly by the primary firing pin. The requirement for strength is also difficult to meet and must be taken into account not only in the design but in the type and quality of material specified.

2. *General requirements for safety in handling and stowage*, which are similar to those for gun projectile base fuzes. These requirements arise from the fact that rocket base fuzes, like projectile base fuzes, are shipped installed in the high-explosive head. In addition the special requirements mentioned in the preceding section must be satisfied. Effective moistureproofing of base fuzes is also obviously essential to prevent corrosion of working parts and deterioration of explosive components.

1.07. GENERAL REQUIREMENTS FOR POINT-DETONATING FUZES.—The basic func-

tional and safety requirements for point-detonating rocket nose fuzes are the same as for similar projectile fuzes. Point-detonating fuzes are usually designed to detonate the head¹ instantaneously on impact. This fact makes the design and material requirements much easier to satisfy than is the case with base fuzes, since, when the fuze is designed to detonate the instant it strikes an object, the strength of parts is not so important. However, if delayed detonation after impact is required of a nose fuze (for example, the AIR-9, 2.09) then the strength factors become very critical. In such a fuze the protection of the explosive components during impact is extremely difficult, and the most severe impact that a delayed-action nose fuze can stand is far less than in a properly designed base fuze. For this reason, and because the presence of a fuze hole in the nose of the rocket head weakens the head, a base fuze is indicated when delayed detonation after penetration of a heavy target is required.

Safety and moistureproofing requirements for nose fuzes are also somewhat less stringent than for base fuzes. This arises from the fact that nose fuzes are usually shipped separately from the heads in sealed containers from which they are not removed until the round is assembled.

1.08. ACCEPTANCE TESTS.—To assure that safety and functional features are maintained in manufacture and loading, sample fuzes chosen at random from each production lot² are subjected to certain tests before the lot is accepted. These tests are known as acceptance tests and are in addition to any special tests of specific features made during manufacture and loading as a part of inspection.³

1.081. SAFETY TESTS.—These tests are usually identical with tests of projectile nose and base fuzes. The first three tests listed below are exaggerated simulation of rough treatment and accident during shipment and handling. After these tests the fuzes are disassembled and examined for evidence of (1) functioning of explosive components and (2) any dangerous condition arising from derangement of parts.

1. A *drop test*, in which fuzes assembled in inert-loaded rounds are dropped from an arbitrarily chosen height (25 or 40 ft) on nose, side, and base onto armor plate.

2. A *jolt test*, in which fuzes are mounted in a fixture in a special machine and subjected to 1750 drops in each of various positions from a height of 4 in. onto a leather-covered anvil.

3. A *jumble test*, in which the fuze is placed in a closed rectangular box mounted in a machine which revolves the box around one of its long diagonals at 30 rev/min for 3600 revolutions.

4. A *minimum-arming-distance test* may be specified similar in character to bore-safety tests of projectile fuzes to test delayed-arming features. Since this test is difficult to perform, tests of the functioning of individual features involved are usually made during manufacture instead.

¹ Chemical heads are intended to be burst rather than detonated.

² A production lot usually consists of 2000 fuzes plus samples expended in acceptance tests.

³ For example, arming-pressure tests in pressure-arming base fuzes, tests of detonators for brisance and delay, etc.

1.082. **FUNCTIONING TESTS.**—These tests are intended to show that the over-all functioning of the fuze is satisfactory. Since fuzes differ widely in kind and use, these tests are quite different for different fuzes. In general they are designed to show that the fuze functions properly under the conditions of use for which it is designed. These tests are usually performed with fully loaded rounds. Nose fuzes are tested for high-order functioning on ground or water impact. Base fuzes are tested for over-all functioning on ground or water impact and also for functioning against steel plate. Some tests are made against plate as heavy as the rocket head will withstand and others against light plate for sensitivity. The requirements are high-order detonation at the proper distance behind the plate, depending on the delay element in the particular fuze. Plate tests are usually not used as a criterion for acceptance or rejection of a lot. For ASR and Hedgehog fuzes special tests for arming and firing under water are performed under conditions closely simulating those in which the fuze is used (Chapter 7).

Acceptance tests for functioning present an opportunity to determine the weak points in fuze design and manufacture, provided the duds obtained in these tests are recovered and intelligently and critically examined. By close liaison between design, production, and testing activities, much can be done to correct difficulties which these tests reveal before the production of many lots that include the objectionable features. Mere rejection of a lot or lots because of failure to pass tests, without attempting to learn the specific reasons why the failures occurred, is not constructive.

1.09. **MATERIALS USED IN ROCKET FUZES.**—Materials used in rocket fuzes depend principally on the purpose for which the fuze is designed and the requirements for proper functioning and safety. In general it may be said that the selection of materials is far more critical for base fuzes than for nose fuzes. In base fuzes strength to withstand impact is a paramount consideration. To prevent corrosion and deterioration of moving surfaces, parts made of materials that corrode readily are plated. In nose fuzes that function instantaneously strength is not so important. However, if the fuze is used in a head which also contains a base fuze and it is desired on occasion to launch a round with the nose fuze safe to obtain the delayed action of the base fuze, it is necessary that the nose-fuze body be strong enough to protect the explosive components from deflagration on impact, and not to reduce materially the penetrating power of the head.

Availability and machinability of materials are also important factors and in wartime often outweigh other considerations.

1.10. **TERMINAL BALLISTICS.**¹—The terminal ballistics of a rocket is determined partly by fuze performance and partly by the performance of the rocket head. The purpose of the fuze is to give high-order detonation of the head under the desired circumstances, and in order to gain the optimum effects the design of the fuze and head must be closely related. This is particularly true of rockets for which special heads, such as underwater heads for aircraft rockets, designed for specific uses are developed. The fuze and head are related so closely that for best results it is ad-

¹ By "terminal ballistics" is meant the performance or effectiveness of the rocket on impact with the target.

vantageous to consider the development of their design together. Their designs are interdependent in many ways, particularly in strength, form, size, explosive components, and in the method by which the fuze is attached to the head.

1.11. SPECIFICATIONS FOR ROCKET FUZES.—Ordnance specifications have been prepared for all rocket fuzes standardized for production by the Navy Bureau of Ordnance. These include all specifications for material, methods of manufacture, assembly, inspection, explosive components, loading, and acceptance tests.

Chapter 2

AIR NOSE FUZES

2.00. INTRODUCTION.—The AIR nose fuzes were developed for use with various fin-stabilized rockets launched from ground, ship, and aircraft. AIR signifies “air-arming, impact-firing, rocket” fuze. The fuzes are point-detonating, and the principles of design and operation are quite similar in all AIR’s. The action of wind forces on a propeller after the rocket is launched is the primary means of arming these fuzes, and acceleration (setback) is used as a secondary force. The differences between the fuzes in this series stem from their adaptation to different rockets, except in the cases of the AIR-9, AIR-10, and AIR-11, whose purpose is different from that of the rest of the fuzes in this series.

2.001. COMMON DESIGN FEATURES IN AIR FUZES.

1. In the *safe* position a spring-loaded shutter containing the detonator is held out of line with the rest of the explosive train by a firing pin screwed into the nose of the fuze body. A propeller or arming vane is fixed to the end of the firing pin.

2. In the safe condition the firing pin is prevented from turning by a locking pin, attached to a setback block supported by a spring. In most of the AIR fuzes this pin engages the propeller.

2.002. COMMON FUNCTIONAL FEATURES IN AIR FUZES.

1. Arming is accomplished by a combination of wind and acceleration forces acting as the rocket is launched. Acceleration retracts the setback block, releasing the firing-pin-propeller assembly. The propeller, acted on by the air stream, screws the firing pin out until the shutter is released. The shutter is then rotated into the *armed* position by the shutter spring, and is locked by a detent in such a position that the detonator in the shutter is in line with the firing pin and the lead-in to the booster.

2. The fuzes are point-detonating. With the exception of the AIR-6 and AIR-9 Mod 1 the fuzes are fired by an impact on the firing pin which is sufficient to shear the threads in the nose of the fuze body and drive the firing pin into the primer of the detonator.

2.003. BASIC REQUIREMENTS.—The basic requirements which determined the design and operational features of the AIR fuzes were the following:

1. To detonate the rocket head instantaneously on impact with ground or water in the rocket projectile for which the fuze is designed to operate. The detonation should occur on the surface of the target to secure maximum fragmentation, smoke, or chemical distribution, or blast effects above ground or water.¹

2. To provide adequate safety in handling of the assembled round, that is to meet the safety requirements normally expected of bomb and projectile nose fuzes.

¹ This does not apply to the AIR-9, AIR-10, AIR-11, or the Nose Fuze Mk 145 (modification of AIR-2), all of which contain pyrotechnic delay elements.

3. To provide that arming of the fuze shall not be completed until the round is a safe distance (usually beyond the burning distance of the rocket) from the launcher.

4. To prevent arming of the fuze in event of a failure (blowup) of the rocket motor occurring within the first half of the burning distance and thus to avoid detonation of rounds which malfunction and fall dangerously short.

5. In most cases to maintain extreme simplicity and use readily available and easily worked materials, in order to facilitate immediate quantity procurement.

The first requirement listed above determined that the fuzes would be point-detonating nose fuzes. The sensitivity needed to fire the fuzes at impact on ground or water was usually obtainable by adjusting the length of the threads in the nose plate of the fuze body within narrow limits. In the AIR-6 fuze sufficient sensitivity was not obtainable by the shearing of threads, and a different method was used. The water-discriminating fuzes (AIR-9, AIR-10, and AIR-11) were made insensitive enough not to function on water impact, by greatly increasing the number of threads to be sheared and by eliminating the rigid propeller hub.

To meet general safety requirements the fuzes were designed to be detonator-safe; that is, in the *unarmed* position the detonator is out of line with the rest of the explosive train. To provide safety in handling and shipping, the setback block in the fuzes with exposed propeller (AIR-1, AIR-6) is locked by a safety wire. In the fuzes with a cap covering the propeller for waterproofing (AIR-8, AIR-12) no safety wire through the setback block is used; instead, the cap spring bears on the propeller and prevents it from turning. Since in all the AIR fuzes the detonator shutter is held out of line with the rest of the explosive train by the firing pin, any serious damage incurred by dropping, etc. is very likely to jam the firing pin in such a manner as to render it inoperative and therefore safe. Such damage is incurred on the 25-ft drop tests, to which samples of all production lots are subjected for acceptance.

The third requirement, that the fuzes arm at a safe distance from the launcher, is met in the fuzes for rockets fired from stationary launchers by so adjusting the efficiency of the propeller that the number of turns required for the firing pin to release the shutter is not completed until the end of burning. The burning distance varies, not only for different rockets, but for different motor temperatures. For the fuzes used in rockets launched from aircraft an additional safety against early arming is provided (except in the Mk 148) by a setback block containing a pin which, as long as the rocket is accelerating, locks the detonator shutter in the *safe* position even though the firing pin may have advanced and released the shutter long before the end of burning. In either case, as long as the detonator shutter is held in the *safe* position, almost any nose impact which the rocket sustains during this time will drive the firing pin back alongside the shutter without firing the fuze and will render the fuze inoperative and harmless thereafter.

The fourth requirement, that fuzes on rounds which malfunction because of motor blowup or tumbling during the first part of the burning time do not continue to arm, is more important for rockets launched from stationary launchers than for those launched from aircraft. The method used in these fuzes is to adjust

the efficiency of the propeller and the "setting"¹ so that the firing pin completes the requisite number of turns to free itself from the locking pin as close to the end of burning as is practicable. Since the burning time of rockets is shortest at high motor temperatures, the propeller and the setting are empirically adjusted barely to permit arming at the highest service temperatures. Aside from the general design problems (propeller-vane pitch, etc.) involved in meeting the requirements inherent in this method of obtaining a safety against arming under abnormal conditions, three factors are particularly critical and must be carefully controlled in the manufacture, assembly, and inspection of the AIR fuzes. Since the adjustments involved are critical, all fuzes must be consistent in operation, within rather narrow limits. These factors are as follows:

1. The setting of the propeller-firing-pin assembly described above must be carefully controlled to insure that at assembly it is held within the limits specified for the fuze.

2. Since the spring-loaded detonator shutter bears against the rotating firing pin, frictional forces are introduced which must not be so large as to exert undue drag on the firing pin, particularly during the critical first few turns; therefore, the shutter spring must be so designed as to exert the minimum torque consistent with positive action. For this reason all surfaces involved must be smooth, and sometimes burnishing of plating is required. Inspection of the free action of the firing pin and shutter must be made during assembly.

3. The firing-pin threads must be a "free-running" fit in the threads of the nose plate of the body. A consistent and loose fit is essential. This is not obtained by specifying standard classes of thread fits, since these permit small clearances. The most practical solution obtained was to specify a somewhat smaller nominal diameter for the male firing-pin thread than for the female thread in the fuze body and to hold each of these within small tolerances. Thus the fit was of the proper looseness and yet consistent. For example, in the Mk 149 (AIR-8) fuze, the thread of the firing pin is specified as 0.3075-in.-32NS-3-LH and that in the nose plate as 0.3125-in.-32NS-3-LH. Burnishing the plated firing-pin threads was also found to be desirable to insure a free-running fit.

Two serious shortcomings are inherent in the design of some of the AIR fuzes:

1. Moistureproofing of the AIR fuzes is inadequate except for those with the nose caps covered by a cap which is removed by an arming wire only when the round is fired.

2. Most of the AIR fuzes, with the exception of those specifically designed for use in aircraft rockets, do not fire consistently at small angles of impact (less than 20°). This limitation is fortunately not serious, since most of the rockets in which these fuzes are used are always fired at high elevation.

Tests performed in developing the AIR fuzes are adequately covered by numerous reports published in the CIT Weekly Progress Reports (PMC).

¹ By "setting" is meant the number of turns of the firing pin required, while the setback block is retracted during acceleration, for the firing pin to advance sufficiently to prevent re-engagement of the vane-locking pin with the stops on the propeller hub.

2.01. AIR-1 FUZE

Rocket in which used

4.5-in. Barrage Rocket, with 2.25-in. Motor Mk 7 and 4.5-in. Head Mk 1

Dimensions and weight

Over-all length: 3.95 in.

Thread: 1.50"-12NF-2

Weight: 0.8 lb

Material

Body: aluminum

Propeller: steel

Propeller guard: steel

Firing pin: steel

Explosive components

Detonator: from M52 fuze

Lead-in: from M52 fuze

Booster: from M52 fuze

2.011. GENERAL.—The AIR-1 fuze is a modified Army M52 point-detonating fuze, designed for use in the first CIT model of the 4.5-in. Barrage Rocket. At the time this fuze was designed there was immediate need for 3000 fuzes for service use in the barrage rocket, but no bomb or projectile fuze directly applicable to this rocket was in existence. The reason for modifying an existing fuze rather than designing and producing a completely new one was that the major parts could be readily procured.

The point-detonating M52 fuze is used in the 60-mm and 81-mm mortars. It arms by setback only when the projectile is fired. Setback forces a detent out of the bore-rider pin, which is thrown out of the fuze body when the projectile leaves the mortar and thus releases the spring-loaded detonator slider. The slider then moves across the body until it is stopped and locked by another detent in such a position that the detonator is in line with the firing pin and lead-in. On impact the firing pin, attached to a striker protruding from the nose of the fuze body, is driven into the primer of the stab-type detonator to fire the fuze.

In modifying the M52 fuze into the AIR-1 for use in the 4.5-in. Barrage Rocket it was necessary to change the means of arming, since the acceleration of the rocket was too small to be used as the sole arming force. The general method of arming used in the AIR-1, a combination of wind and acceleration forces, is the same as was used in the later AIR fuzes.

2.012. DESCRIPTION OF AIR-1 FUZE.—The setback detent in the M52 fuze, which holds the bore-rider pin in the *safe* position, is removed and replaced by a latch. This latch is locked in place by the same safety wire used in the M52 fuze. The striker-firing pin assembly in the M52 is replaced by a propeller-firing-pin assembly, and the space in the nose of the fuze body formerly occupied by the striker head and anticreep spring is used to house a setback block. The nose cavity in the fuze body is closed by a brass nose plate into which the firing pin is screwed. In the *safe* position the firing pin engages the bore-rider pin, the detonator slider, and also the

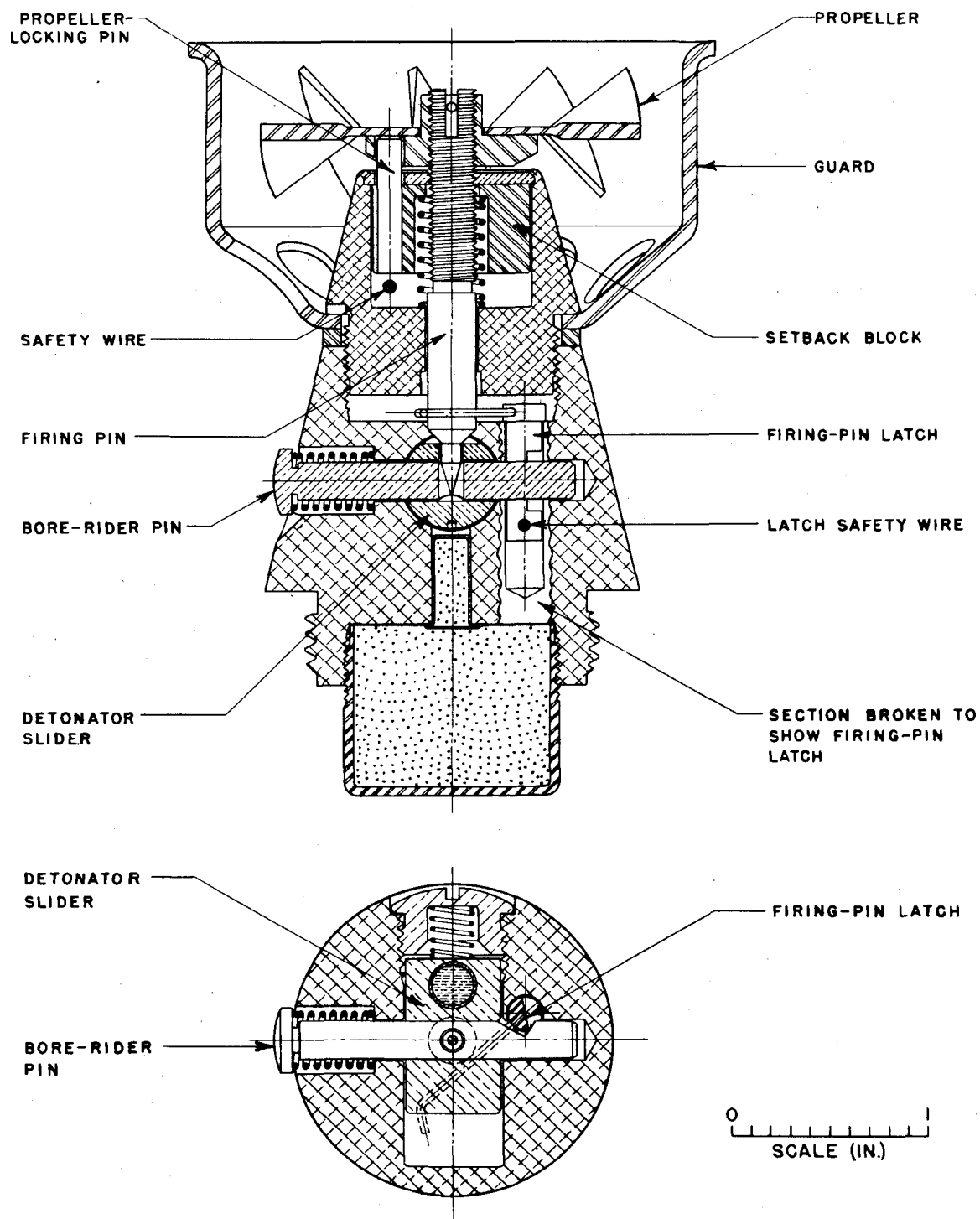


FIG. 1. AIR-1 fuze, unarmed.

latch. A locking pin attached to the setback block engages a hole in the propeller hub and prevents it from turning. A second safety wire locks the setback block.

2.013. **ARMING.**—After the fuze is assembled in a round but before the round is loaded in the launchers the two safety wires, which lock the latch and the setback block respectively, are removed. When the rocket is launched acceleration retracts the setback block, releasing the propeller, which begins to rotate under action of the air stream and to withdraw the firing pin. As the firing pin screws out in the threads of the nose plate its point disengages the detonator slider, the bore-rider pin, and the latch. Finally the firing pin turns freely when the undercut at the end of the threads reaches the nose plate. Release of the latch permits the bore-rider pin to fly out and the detonator slider to move into the *armed* position. At ambient temperature the fuze arms at about 150 ft from the launcher, well beyond the burning distance (about 60 ft at 70°F) of the rocket.

2.014. **FIRING.**—On impact with water or ground the firing pin is driven back, shearing the threads in the brass nose plate, and the point of the firing pin stabs the primer of the detonator, initiating the instantaneous explosive train.

2.015. **REMARKS.**—A total of about 6000 AIR-1 fuzes were manufactured by CIT between August and December, 1942, and delivered to the Navy for service testing in the first model of the 4.5-in. Barrage Rocket. They were loaded with M52 explosive components by Picatinny Arsenal. The fuze was never standardized for Navy production and no mark number was assigned to it; early in 1943 it was replaced by the Mk 137 (AIR-2). The AIR-1 and Mk 137 fuzes are not interchangeable.

2.02. AIR-2 (MK 137) FUZE

Rocket in which used

4.5-in. Barrage Rocket, with 2.25-in. Motor Mk 8 or 9, and 4.5-in. Head Mk 2, 3, 5, or 7

Dimensions and weight

Over-all length: 2.965 in.

Thread: 1.50"-12NF-2

Weight: 0.8 lb

Material

Body: brass

Propeller: steel

Propeller guard: steel

Firing pin: steel

Explosive components

Detonator: instantaneous

Lead-in: tetryl

Booster: tetryl (9 gm)

General arrangement drawing

BuOrd Drawing No. 437988 (Mk 137 Mod 2)

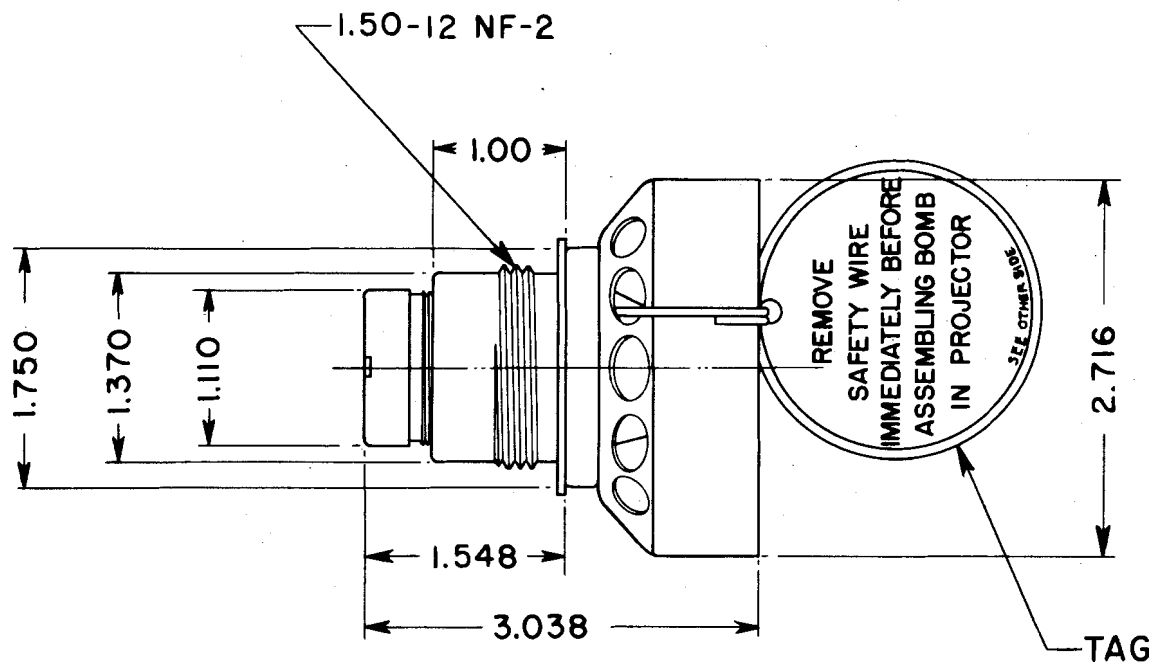
2.021. GENERAL.—The AIR-2 fuze (Navy designation Mark 137) was designed to succeed the AIR-1 fuze in the 4.5-in. Barrage Rocket.¹ It was designed specifically for use in this rocket, and its principle of operation has served as the prototype for several later AIR fuzes.

The original CIT design of the AIR-2 fuze was submitted to the Naval Ordnance Laboratory in September, 1942, for analysis and modification. A number of alterations in design were made by the Naval Ordnance Laboratory, the principal one being the substitution of a detonator shutter operated by a torsion spring for one operated by a compression spring similar to that of the SIR (Mk 139) fuze. The design described here is essentially that received from the Naval Ordnance Laboratory, with numerous additional modifications which tests and manufacturing processes later showed to be necessary.

The general methods of arming and firing the AIR-2 fuze are similar to those used in the AIR-1, but the mechanism is made simpler by the elimination of the irrelevant features which the AIR-1 inherited from the M52 mortar fuze.

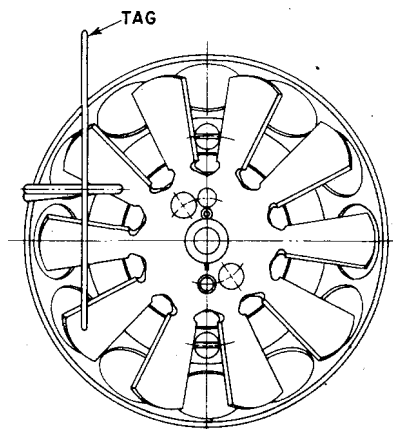
The 4.5-in. Barrage Rocket was designed principally for firing from landing craft to provide a barrage on beaches immediately prior to landing operations. The rockets were usually fired at maximum range (1100 yd). Development of the Mk 7 automatic launcher led to more widespread applications, and permitted the rockets to be fired from several types of land and amphibious vehicles in addition to landing craft. Since the primary purpose of the rocket was to provide a heavy barrage over a relatively wide area, and since the accuracy and velocity of the rocket, and the type of head used, did not appear to justify use of a delayed-action

¹ For characteristics of the 4.5-in. Barrage Rocket see Table 1, Ch. 1.



(ALL DIMENSIONS ARE MAX.)
WEIGHT 14.25 OUNCES

FIG. 2. Outline and end views of AIR-2 fuze (Nose Fuze Mk 137 Mod 2).



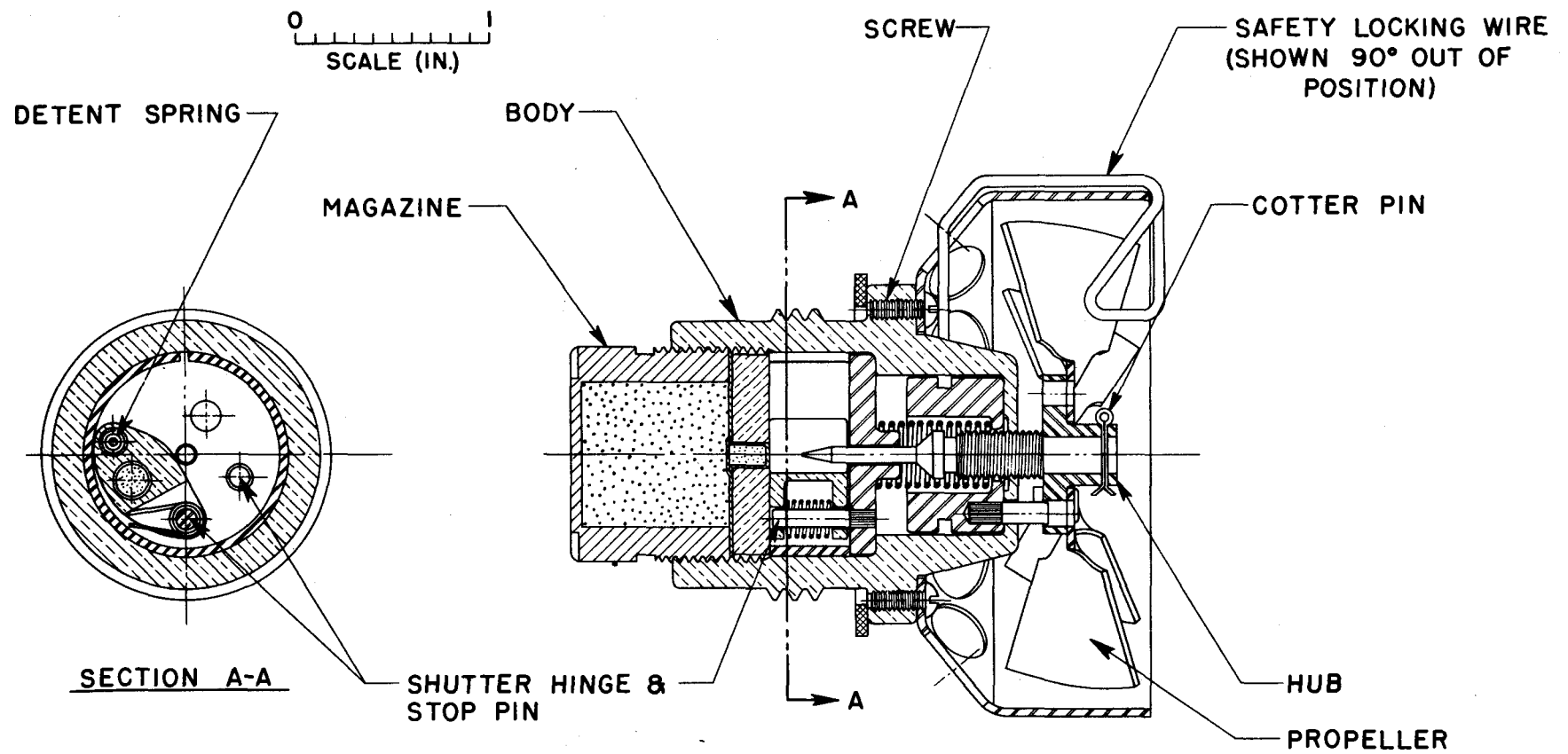


FIG. 3. AIR-2 fuze, unarmed.

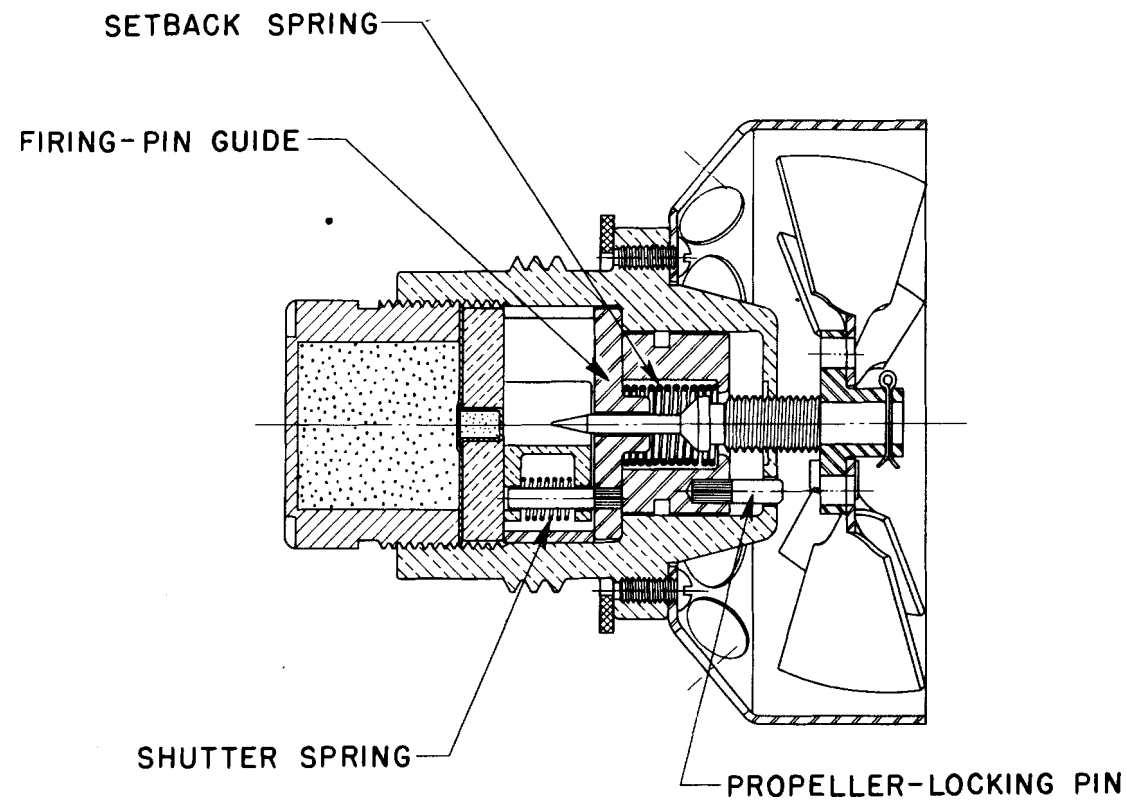


FIG. 4. AIR-2 fuze, showing motion of parts during burning of rocket motor.

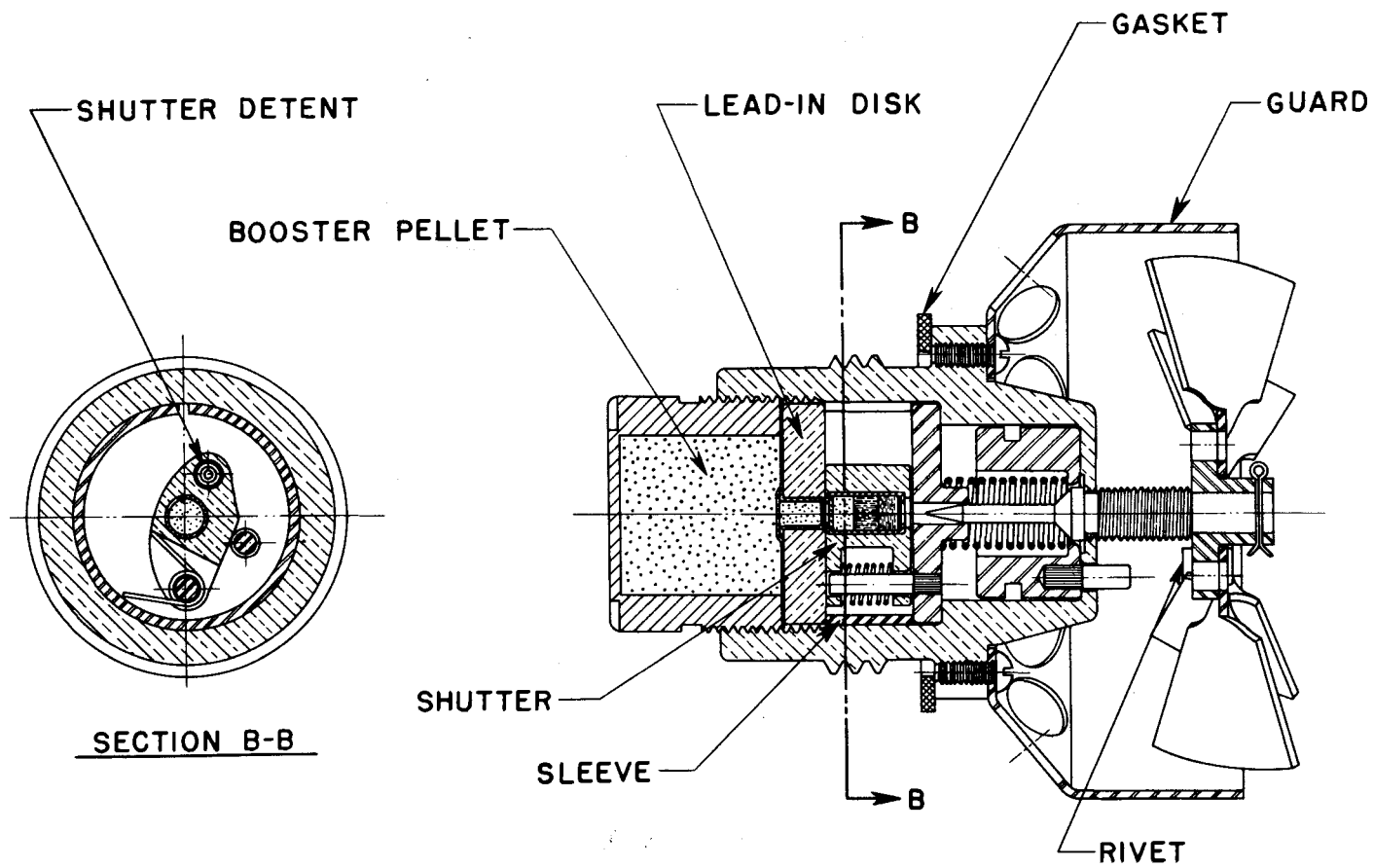


FIG. 5. AIR-2 fuze, armed.

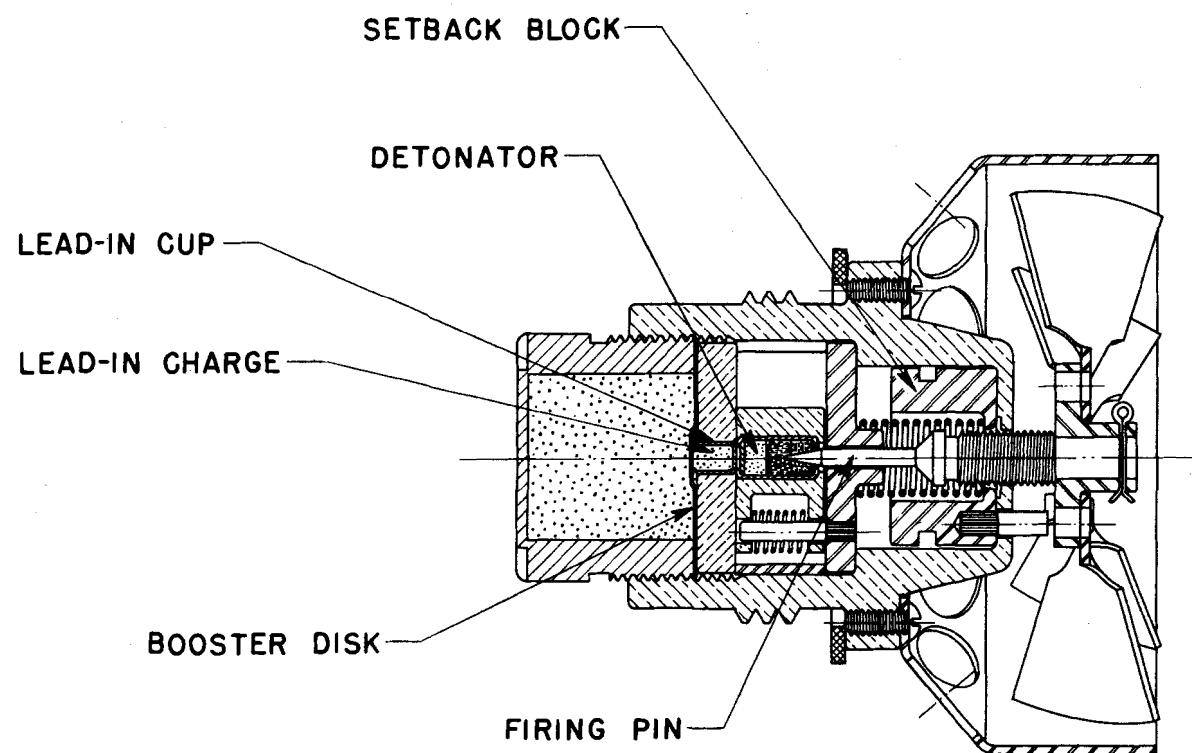


FIG. 6. AIR-2 fuze, fired.

fuze, the most effective tactics called for a superquick nose fuze to detonate the rocket on the surface of the ground for maximum blast and fragmentation effects.

For special purposes, where a delayed-action firing was required, the Nose Fuze Mk 145 was developed by the Naval Ordnance Laboratory. The Mk 145 is a modification of the AIR-2; it utilizes a detonator with a percussion primer and a 0.02-sec delay element developed especially for this fuze.

A history of the development of the Mk 137 fuze is given in NavOrd Report No. 23-44, published in September, 1944, by the Naval Bureau of Ordnance. It may also be traced in CIT Weekly Progress Reports (PMC) published during 1942, 1943, and 1944.

2.022. DESCRIPTION.—A firing pin protruding from the top of the fuze body is screwed into the body and extends through the firing-pin guide. Fitted around the firing pin is a setback block and spring. A propeller-locking pin extends from the setback block through the top of the fuze body into an opening in the propeller hub. Immediately below the firing-pin guide a detonator shutter is mounted on a pin in such a manner that it is rotated by action of the shutter spring when the firing pin is withdrawn. A booster lead-in disk is assembled below the shutter.

A sleeve forms a cavity around the shutter, separating the lead-in disk and firing-pin guide so that the shutter is allowed sufficient clearance for rotation. In early models this sleeve was secured by a setscrew through the fuze body. In later models the sleeve is split and expanded to fit tightly in the fuze body, and the setscrew is omitted. The magazine containing the booster charge is screwed into and closes the fuze body. The propeller is set on the top of the firing pin and is secured to it by means of a cotter pin. A propeller guard affixed to the top of the fuze body by four screws protects the propeller. A safety locking wire is provided to lock the setback block and the propeller and so prevent arming.

2.023. ARMING.—When the fuze has been assembled in a round the safety wire is withdrawn and the round is then placed in the launcher. When the rocket is fired, the setback force acting on the setback block forces the block to the rear, compressing the setback spring. This movement withdraws the propeller-locking pin from engagement with the propeller hub. The air stream acting on the propeller causes it to rotate and so unscrew the firing pin from the fuze body. The setback force acts on the setback block only during burning of the rocket motor, after which the setback spring returns the block to its original forward position. However, the firing pin has meanwhile unscrewed from the fuze body sufficiently to prevent re-engagement of the propeller-locking pin with the propeller. The efficiency of the propeller, which depends on the pitch, number, size, and weight of the vanes, is so adjusted that under the most unfavorable conditions (short burning distance at maximum service temperature) the firing pin makes the number of revolutions required (more than one but not more than one and one-half) to prevent re-engagement of the propeller-locking pin just before the end of burning of the rocket.

Rotation of the propeller continues to unscrew the firing pin, until an unthreaded section is reached and a shoulder on the pin comes up against the top of the fuze body, after which the propeller-firing-pin assembly rotates freely. Before the firing pin is unscrewed it holds the detonator shutter to one side, so that the detonator is

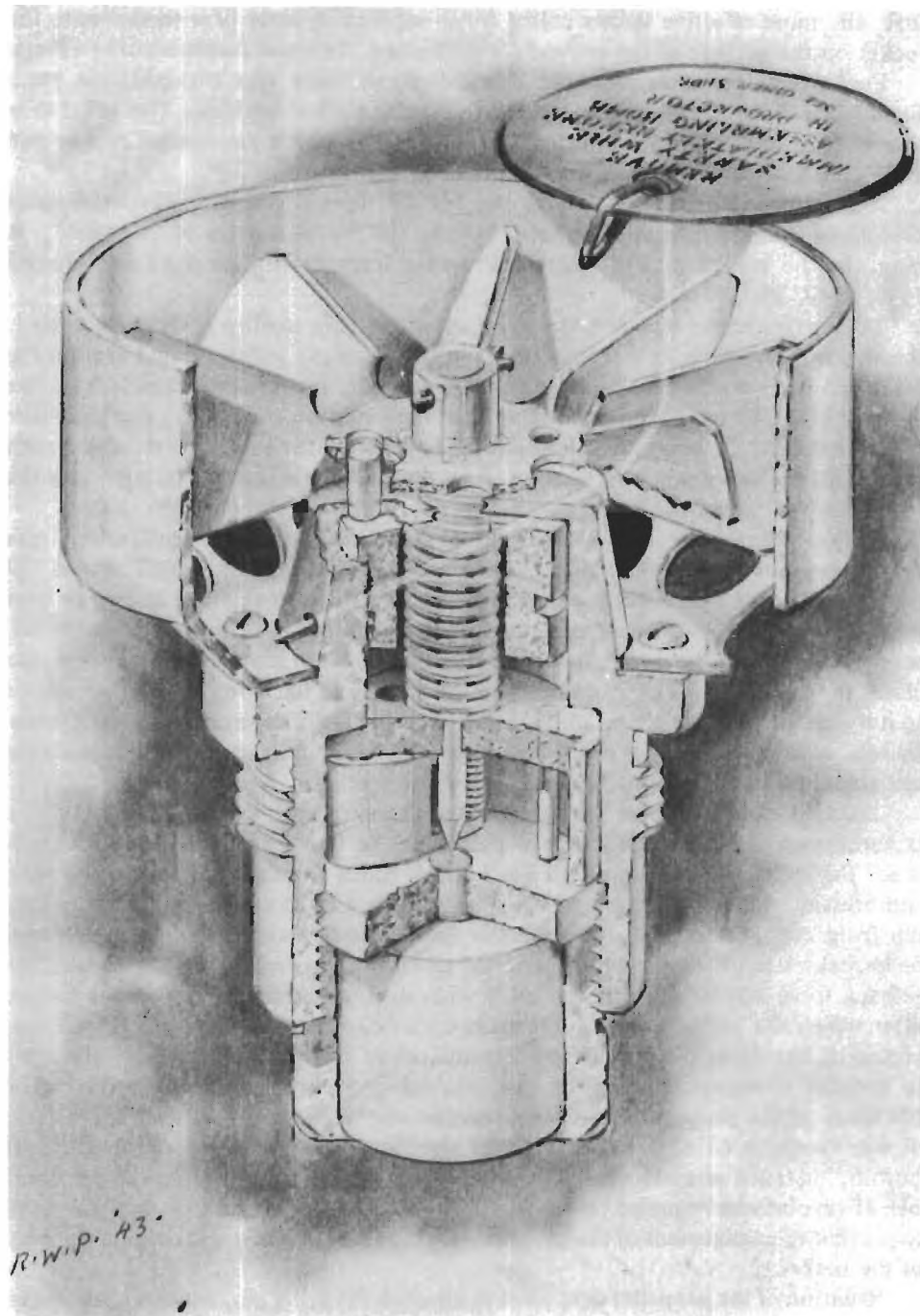


FIG. 7. AIR-2 fuze, unarmed, as shipped, with safety wire in place through the body and setback collar (Nose Fuze Mk 137).

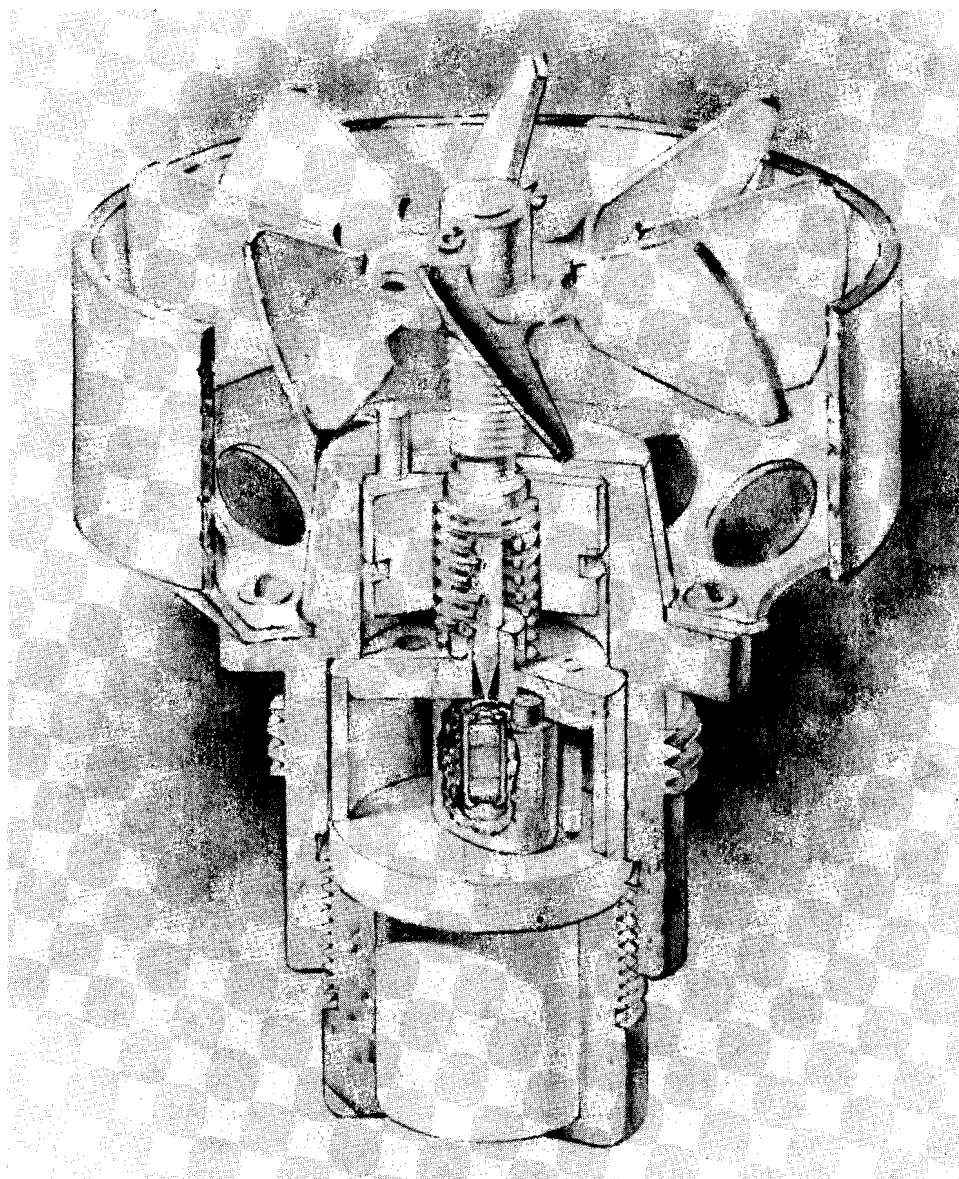


FIG. 8. AIR-2 fuze, armed (Nose Fuze Mk 137).

out of alignment with the firing pin and booster lead-in. When the firing pin unscrews the shutter is released, and the shutter spring rotates the shutter to a position against a stop pin. A shutter detent then engages a hole in the firing-pin guide, thus locking the shutter in this position. The detonator is now aligned with the firing pin and the booster lead-in, and the fuze is fully armed. The arming distance of the fuze in the 4.5-in. Barrage Rocket is about 125 ft.

2.024. **FIRING.**—On impact, the fuze is fired when the firing pin is driven back, shearing the threads in the nose of the body, and stabs the primer of the instantaneous detonator. In the 4.5-in. Barrage Rocket the fuze will fire on impact with ground or water. The requisite sensitivity is achieved by holding the length of the thread for the firing pin in the brass fuze body to 0.055 in. + .000 in. or — .005 in. The minimum angle of impact on soft ground for consistent firing is 15°. On hard surfaces it is probably somewhat larger.

2.025. **REMARKS.**—About 42,000 Mk 137 fuzes were manufactured by CIT for delivery to the Navy during 1943. These differed from those manufactured by BuOrd contractors in that the propeller had eight instead of ten vanes and in the method of forming the ratchet stops on the propeller hub. Later additional minor changes were introduced in BuOrd production, the latest type being designated Mk 137 Mod 2.

Early fuzes had only one hole to engage the propeller-locking pin, and one stop on the hub. Because the setting of the firing-pin-propeller assembly is critical, two sets of holes and stops were specified to permit closer adjustment at final assembly of the fuze. The following factors are associated with the adjustment or setting of the propeller-firing-pin assembly:

1. Number of threads per inch on firing pin.....28
 2. Minimum number of turns of firing pin required to disengage propeller-locking pin from ratchet stop (2 stops on opposite sides) on hub.....1 (3 stops)
 3. Maximum number of turns of firing pin required to disengage locking pin.....1.5 (4 stops)
 4. Number of turns of firing pin required to arm fuze completely.....
- approximately 8

The Mk 137 fuze is not waterproof. Holes for the propeller-locking pin and safety locking wire readily admit moisture to the inner parts. To correct this a modification was designed which contained an internal setback-operated firing-pin lock similar to that used in the AIR-9. The safety wire, instead of running through a hole in the fuze body, was inserted between the arming vanes through holes in the guard; thus the only holes in the fuze body were those into which the magazine and firing pin screwed. This fuze underwent preliminary tests satisfactorily¹ but was never standardized for production.

A modification of the Mk 137 fuze was developed for the fast-burning 4.5-in. Barrage Rocket. This rocket was developed to replace the standard 4.5-in. BR in an attempt to reduce the dispersion, a result which was achieved by reducing the burning time and burning distance (see Table 1, Ch. 1). Other characteristics were essentially the same as for the standard BR. Arming failures were obtained with the standard Mk 137 fuze in the fast-burning BR at temperatures over 70°F, as was to be expected, since the burning time of this rocket at 70° is equivalent to that of the standard BR at about 130°F. The fuze developed for the fast-burning rocket was identical with the Mk 137 fuze except that the steel propeller of the AIR-2, with vanes of 30° pitch, was replaced by an aluminum propeller with vanes of 45°

¹ See following CIT/PMC reports: 2.42, 23 July 1944, Part 1, p. 1; 2.43, 30 July 1944, Part 1, p. 2; 2.45, 13 August 1944, Part 1, p. 1.

pitch. This increased the efficiency of the propeller and reduced its inertia so that the optimum condition for arming was achieved, namely, that the firing pin was advanced sufficiently to prevent re-engagement of the propeller-locking pin just before the end of burning of the rocket at the maximum service temperature (120°F). Neither the fuze nor the fast-burning BR was standardized for production.

If the 4.5-in. Barrage Rocket with the Mk 137 fuze is fired through foliage which is closer to the launcher than the arming distance of the fuze (approximately 125 ft), the propeller is likely to be damaged to such an extent that arming is not completed and the round becomes a dud. To overcome this limitation, for special conditions, a brush guard was developed to protect the propeller. This consisted of a strong wire cage, conical in shape, which fitted over the propeller guard and seated against the nose of the rocket head. This guard could be applied in the field if conditions of firing called for its use. The brush guard was not standardized for production; however, preliminary tests indicated that it was effective in preventing damage to the fuze on passing through light foliage, but not on impact with branches heavy enough to deflect the round or cause it to tumble.¹ The guard interfered to a certain extent with the wind stream impinging on the propeller and made arming uncertain at temperatures over 110°F.²

Another accessory that was tested with the Mk 137 fuze was a "daisy cutter." This consisted of a Dural rod $\frac{1}{4}$ in. in diameter and about 6 in. long, which was attached to the end of the firing pin by means of a clip. The purpose of the rod was to initiate the fuze before the head penetrated the ground and thus increase the effective fragmentation above ground. A comparison of craters formed by rounds using the rod with craters made by rounds with standard fuzes indicated that the fuzes with the rods were detonated above the surface of the ground.³

The Mk 7^{1/2} automatic launcher was developed after the Mk 137 fuze was standardized and in service use. Tests of the 4.5-in. BR with the Mk 137 fuze in this launcher revealed that failure to follow drawings accurately in the manufacture of the ratchet stop and propeller-locking pin and in the setting of the propeller-firing pin assembly⁴ caused arming of the fuze on the launcher. In the automatic launcher the rounds are stacked in a magazine one above another, and as the lowest round is fired the next round drops suddenly into the firing position and the remaining rounds follow. The rounds are stacked in the launcher at the angle of elevation (usually 45°) used for firing. Thus as the rounds drop into position the fuzes are subjected to a jar with a component along the fuze axis, and at the same time to the blast from the nozzle of the round that is just leaving the launcher. These effects, particularly the blast, are greatest for the round that is dropped into the firing position. Thus, in the action of the automatic launcher itself are inherent the two forces which are required to arm the Mk 137 fuze. The setback block may be retracted momentarily by the jar, and at the same time the blast from the fired

¹ CIT/PMC 2.30, 30 April 1944, Part I, pp. 2-3.

² CIT/PMC 2.31, 7 May 1944, Part I, p. 1.

³ CIT/PMC 1.85, 13 June 1943, 1 m, pp. 2-4.

⁴ CIT/PMC 2.5, 7 November 1943, 1 m, pp. 37-38; CIT/OIC 12.2, 3 November 1943; OIC 12.2, 6 November 1943; OIC 12.3, 15 November 1943.

round strikes the propeller. Since the jar is of very short duration the setback block is retracted only momentarily (if at all), and the vane-locking pin immediately returns to engage the ratchet stops before the propeller has been rotated appreciably by the action of the blast. Since the passing of from 3 to 4 stops is required to free the propeller, the vane-locking pin will re-engage a stop and prevent the fuze from arming. Extensive tests showed that to insure safe performance of the fuze in automatic launchers careful attention in manufacture and assembly was required to insure that the following features were maintained:

1. A ratchet stop having a square face and a height within the tolerance specified on the drawings, to provide positive re-engagement with the vane-locking pin should the pin momentarily free the propeller and the propeller start rotating under action of the blast.
2. A radius on the end of the vane-locking pin less than a certain maximum to insure positive engagement with the ratchet stop.
3. Accurate setting of the propeller-firing-pin assembly to provide for the one to one and one-half turns of the firing pin which are necessary for completely disengaging the vane-locking pin. The above discussion illustrates the importance of small and apparently minor features of fuze design and manufacture.

An important modification of the Mk 137 fuze was developed by the Naval Ordnance Laboratory and designated the Nose Fuze Mk 145. This fuze was developed to fill a requirement for detonation of the 4.5-in. BR after water impact but several feet below the surface, with the purpose of detonating underwater mines and demolition obstacles. Since this requirement called for delayed-action firing, the Mk 137 fuze was modified to take a new detonator containing a 0.020-sec black powder delay element. This detonator was generally similar to the delay detonator used in projectile base fuzes, except that all the components were enclosed in a single case closed by a crimp; thus, the detonator assembly could be placed in the small hole available in the shutter in the same manner as an instantaneous detonator. The detonator assembly consisted of a percussion primer and anvil, an expansion space, the black powder delay element, and a relay detonator of lead azide. A round-pointed firing pin was substituted to initiate the percussion of this detonator and to prevent puncturing of the primer cover by the firing pin on impact. The firing pin was made in two pieces fastened by a shear wire, so that on impact the two parts telescoped. With minor changes this detonator was later adopted for use in many of the PIR base fuzes. Since the 4.5-in. BR with the Mk 145 proved inadequate for the purpose originally intended, this fuze was produced in only limited quantities; however, tests showed that it was capable of consistent functioning on ground impact, its delayed firing action causing large craters.

Another adaptation of the Mk 137 fuze was for use in smoke and incendiary 4.5-in. Barrage Rockets. For this purpose the booster magazine of the fuze was removed and was replaced by a threaded adapter containing a tetryl burster tube to open the chemical head. The fuze of this type used in the incendiary head had a 0.380-in. diameter burster tube and was designated the Nose Fuze Mk 132; that for the smoke (FS or WP) heads had a burster 0.630 in. in diameter, and was designated the Nose Fuze Mk 154.

2.03. AIR-3 FUZE

Rocket in which used

7.0-in. Chemical Warfare Rocket

Dimensions and weight

Over-all length (without burster): 2.9 in.

Thread: 1.700"-14NS-2

Weight (without burster): 1.1 lb

Material

Same as for AIR-2

Explosive components

Detonator: from Mk 137 fuze

Lead-in: from Mk 137 fuze

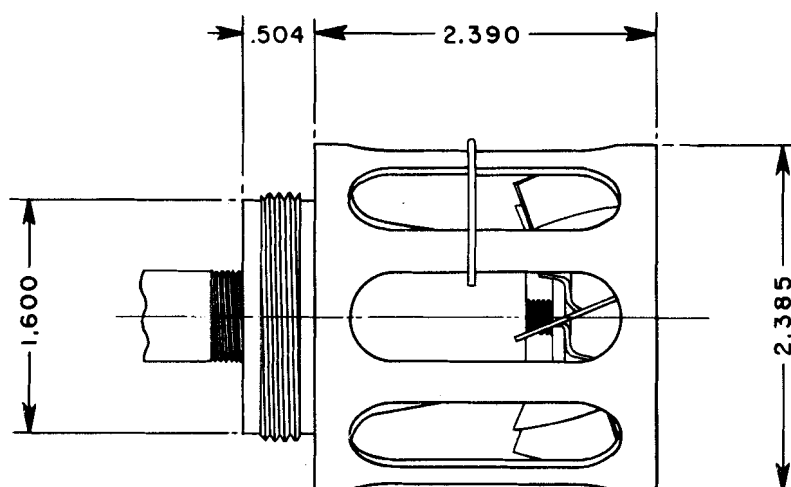
Burster: tetryl

General arrangement drawing

CIT Drawing B2-01

2.031. GENERAL.—The AIR-3 fuze was developed for use with the 7.0-in. Chemical Warfare Rocket; this rocket was replaced by the 7.2-in. CWR, which had essentially the same characteristics. The AIR-5 (Mk 147) fuze was designed for use in the 7.2-in. CWR.

Effective distribution of smoke or chemicals used in the 7.0-in. CWR required an instantaneous point-detonating fuze to initiate a burster tube (tetryl) running through the center of the thin-walled head, which contains the chemical filler. Success of the AIR-2 fuze in the 4.5-in. Barrage Rocket indicated that a fuze of



(DIMENSIONS SHOWN ARE MAX.)

FIG. 9. Outline view of AIR-3 fuze.

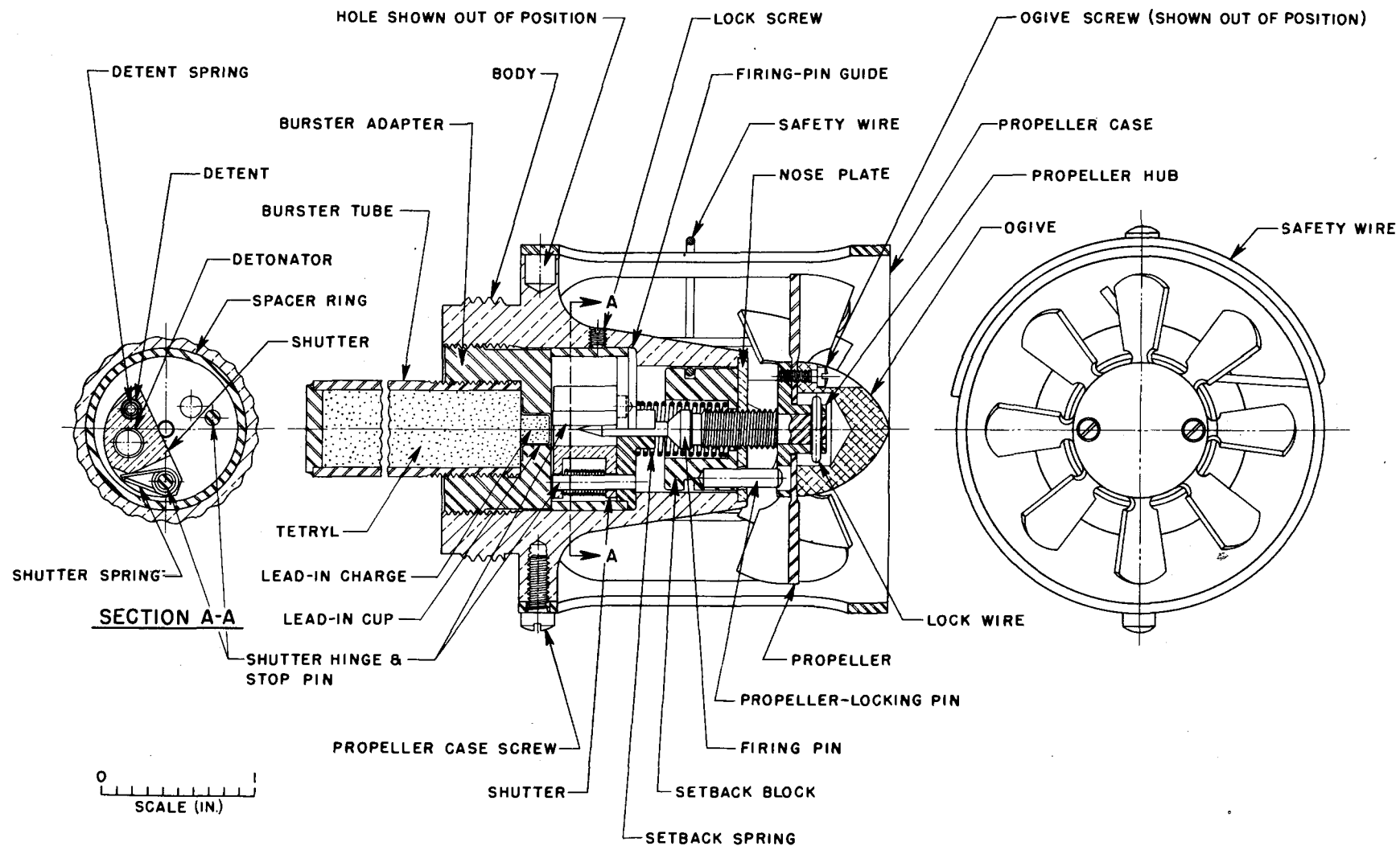


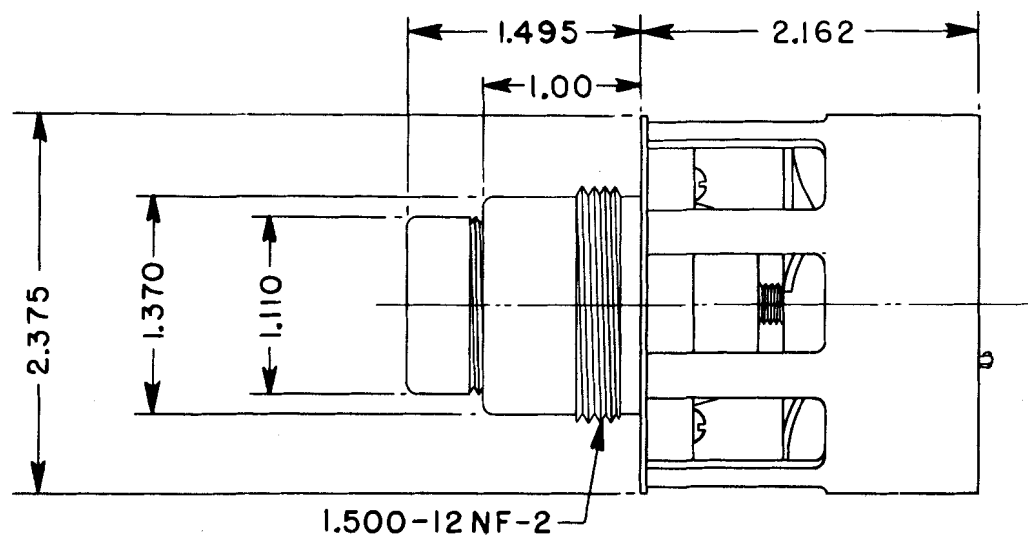
FIG. 10. AIR-3 fuze, unarmed.

the same type should meet the similar requirements of the 7.0-in. CWR.

2.032. DESCRIPTION.—The AIR-3 fuze was modified from the AIR-2 for use in the 7.0-in. CWR; its operating principles and most of its parts are identical with those of the AIR-2. The differences in design are associated with its application to the 7.0-in. CWR. The fuze body is threaded to fit the fuze and burster-well adapter used in the 7.0-in. CWR, the adapter being identical with that of the 4.2-in. Chemical Mortar Projectile. In place of the magazine a burster adapter containing a tetryl lead-in is screwed into the base of the fuze body. The burster adapter contains threads for the standard burster tube used in the 4.2-in. Chemical Mortar Projectile. The propeller was so designed as to give optimum arming characteristics in the 7.0-in. CWR. Because the burning distance and velocity of the 7.0-in. CWR are much greater than those of the 4.5-in. BR, the propeller is smaller than that used in the AIR-2.

2.033. ARMING AND FIRING.—The mechanism and characteristics of arming and firing are similar to those of the AIR-2. The arming distance with the 7.0-in. CWR is about 225 ft.

2.034. REMARKS.—About 600 AIR-3 fuzes were made by CIT for testing in the 7.0-in. CWR by the U. S. Army Chemical Warfare Service. Although the fuze performed satisfactorily in tests it was not standardized, since the 7.0-in. CWR was replaced by the 7.2-in. CWR and another modification of the AIR-2 fuze (AIR-5) was developed for the latter rocket.



(ALL DIMENSIONS ARE MAX.)

FIG. 11. Outline and end views of AIR-4 fuze.

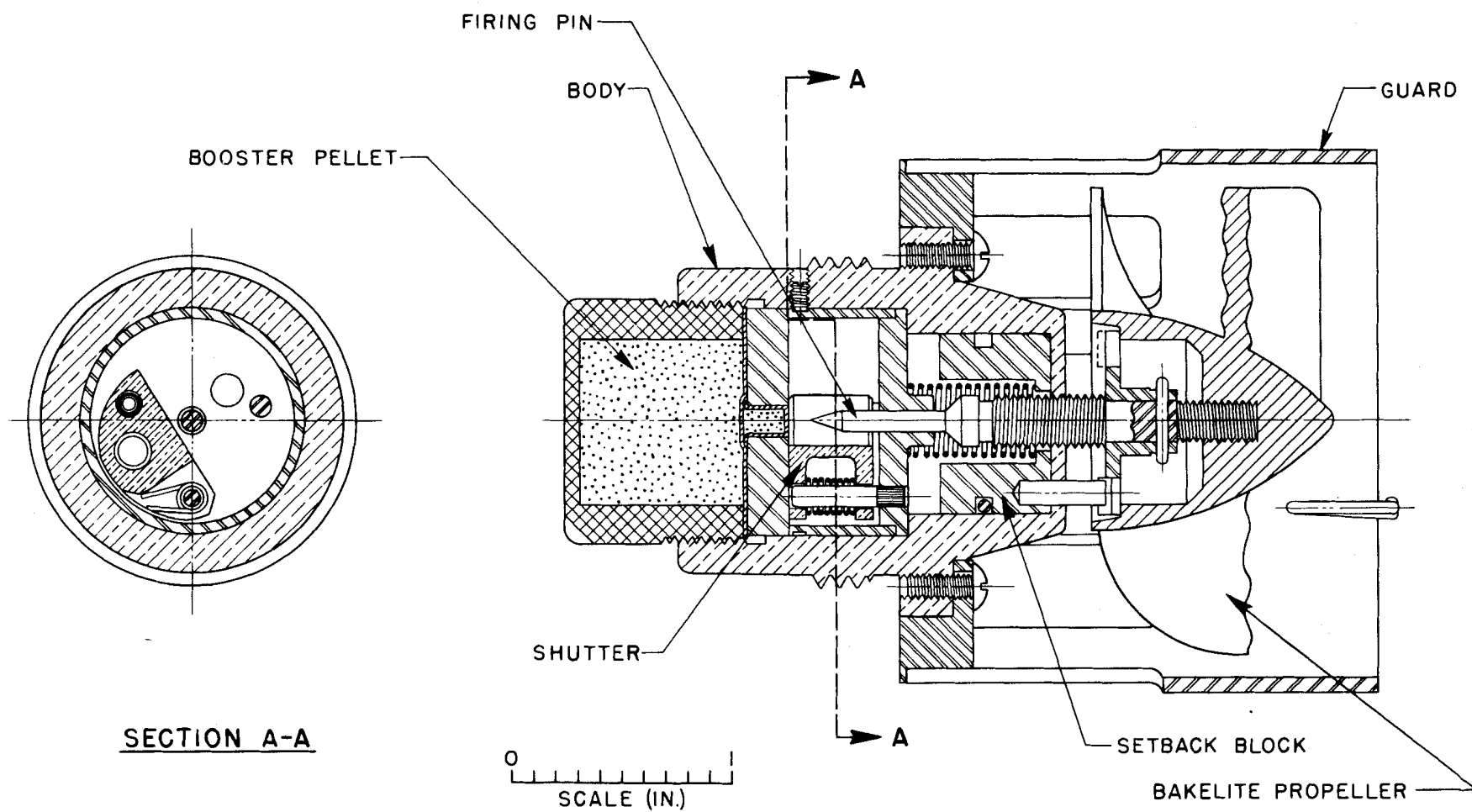


FIG. 12. AIR-4 fuze, unarmed.

2.04. AIR-4 FUZE

Rocket in which used

Fast-burning 4.5-in. Barrage Rocket, with 2.25-in. Motor CIT Model 7 and 4.5-in. Head Mk 2.

General arrangement drawing

CIT Drawing C4-01

2.041. GENERAL.—The AIR-4 fuze was developed for use in the fast-burning 4.5-in. Barrage Rocket, whose burning time and distance were considerably shorter than those of the standardized 4.5-in. Barrage Rocket.¹ The fuze for the fast-burning rocket thus required a more efficient propeller or arming vane than that of the Mk 137 (AIR-2) used in the standard barrage rocket.

One method of obtaining a fuze that would arm on the fast-burning BR was to substitute for the standard steel propeller on the Mk 137 (AIR-2) a light aluminum propeller with vanes of 45° pitch.

The other method attempted was to replace the propeller of the Mk 137 with a light, molded bakelite propeller identical with that used in the AIR-6 and to replace the Mk 137 propeller guard with one suitable to the bakelite propeller. This fuze was designated the AIR-4. No other features of the Mk 137 were altered, since the range and the applications of the fast-burning rocket were the same as those of the standard BR, and therefore no changes in sensitivity, etc. were required.

2.042. REMARKS.—Preliminary tests indicated that the performance of the AIR-4 fuze in the fast-burning 4.5-in. Barrage Rocket would be satisfactory (about 400 of the fuzes were made for testing). This rocket, however, was never standardized for production, and therefore development of the fuze was terminated.

¹ See Table 1, Ch. 1 for performance data.

2.05. AIR-5 (Mk 147) AND AIR-5 MOD 1 (Mk 147 MOD 1) FUZES

Rockets in which used

7.2-in. Chemical Rocket CIT Model 15, with 3.25-in. Motor Mk 5 and 7.2-in. Head Mk 7 (Chem) or Mk 9 (HE)

5.0-in. Aircraft Rocket, with 3.25-in. Motor Mk -7 and 5.0-in. Head Mk 1 (rounds launched from ground or shipboard only)

Dimensions and weight

	AIR-5 (Mk 147)	AIR-5 Mod 1 (Mk 147 Mod 1)
Over-all length with burster:	16.1 in.	16.2 in.
Thread:	1.5"-12NF-2	1.5"-12NF-2
Weight without burster:	0.75 lb	0.70 lb

Material

Same as for Mk 137 fuze

Explosive components

Detonator: from Mk 137 fuze

Lead-in: from Mk 137 fuze

Burster: tetryl (0.630" diam. by 13.75" long)

General arrangement drawings

Mk 147 Mod 0: BuOrd Drawing 394940

Mk 147 Mod 1: BuOrd Drawing 423842

2.051. GENERAL.—The AIR-5 (Mk 147) and AIR-5 Mod 1 (Mk 147 Mod 1) fuzes were developed primarily for use in the 7.2-in. Chemical Rocket. The fuzes differ principally in that the AIR-5 has a fixed propeller guard, whereas the AIR-5 Mod 1 has none, the propeller being protected during shipping and handling by a removable cap identical with that used in the AIR-7 (Mk 148) fuze.

The fuze requirements for the 7.2-in. CWR were the same as for the 7.0-in. CWR, namely, to detonate the burster and distribute the chemical filler of the rocket on the surface of the ground or water. A fuze similar to the Mk 137 used in the 4.5-in. Barrage Rocket was therefore indicated. In addition it was desired that the portion of the fuze extending in front of the nose of the rocket head be small, to give minimum interference with the wind stream and thus minimum reduction of range.

While the AIR-5 fuzes were developed primarily for the 7.2-in. CWR, they are also suitable for use in the 5.0-in. AR launched from the ground or shipboard, because under these conditions the AIR-5 will arm. On the other hand, the AIR-7 (Mk 148) and AIR-8 (Mk 149) fuzes, designed for use in the 5.0-in. AR, do not arm reliably at high motor temperature when the rounds are launched from the ground, since the fuzes were designed for rounds launched from aircraft. For use in the 5.0-in. AR it is necessary to replace the burster adapter in the AIR-5 fuzes with the magazine and booster of the Mk 137 and to use the adapter of the AIR-7 (Mk 148) to adapt the 1.5-in. diameter threads of the fuze to the 1.7-in. diameter threads in the fuze seat liner of the 5.0-in. Mk 1 head.

2.052. DESCRIPTION.—The AIR-5 and AIR-5 Mod 1 fuzes are similar in de-

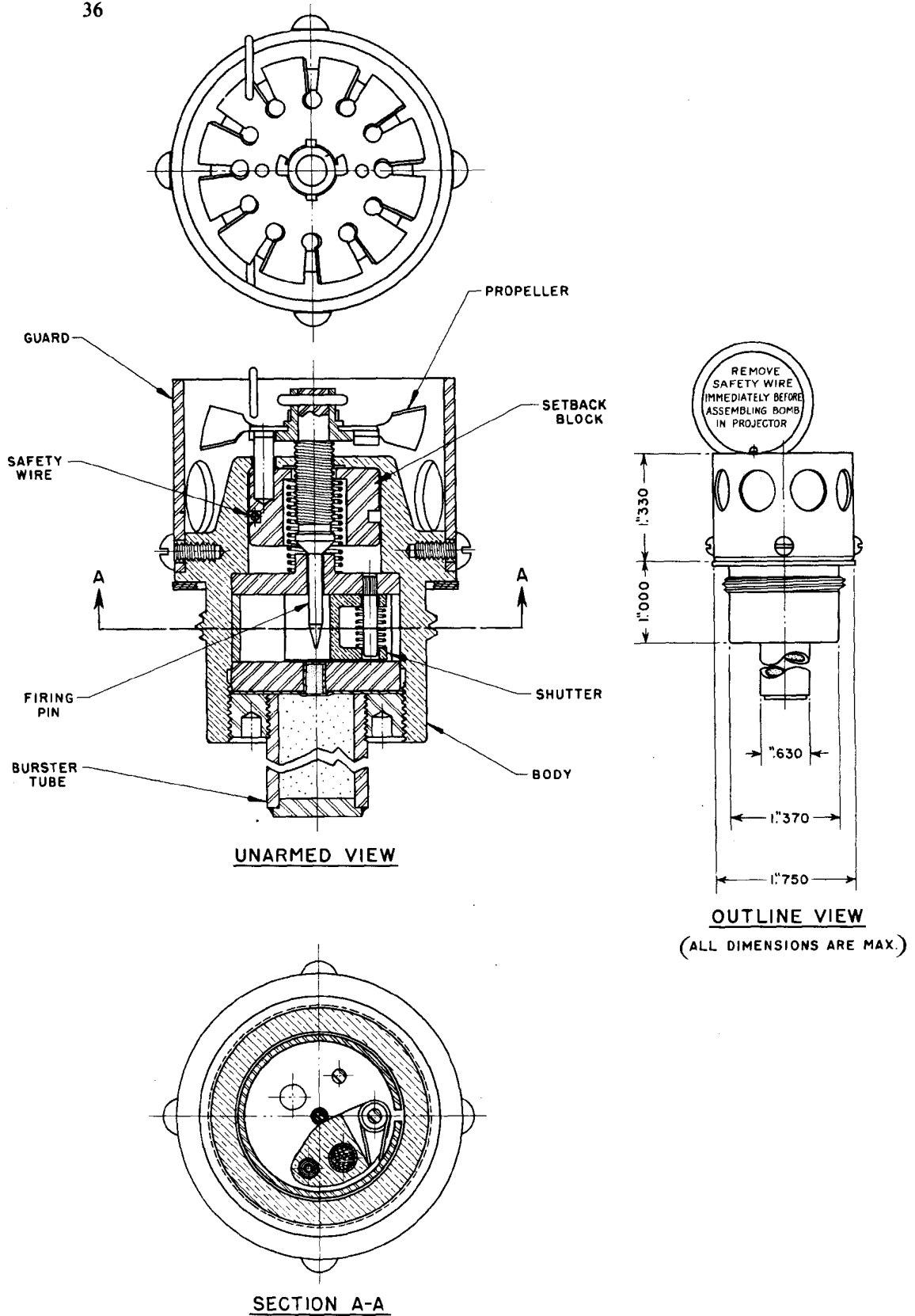


FIG. 13. Outline and assembly drawings of AIR-5 fuze, unarmed (Nose Fuze Mk 147 Mod 0).

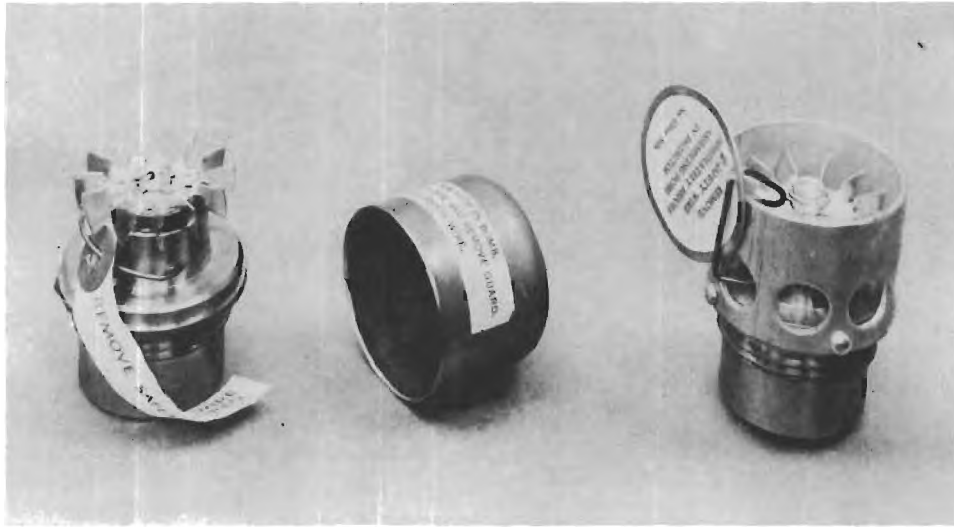


FIG. 14. AIR-5 fuze: *left*, Nose Fuze Mk 147 Mod 1 with shipping cap removed; *right*, Nose Fuze Mk 147.

sign and operation to the AIR-2 (Mk 137), and the parts are identical with the following exceptions:

1. PROPELLER:

a. AIR-5. The propeller is small and light, and the vanes are bent to an angle of 70° .

b. AIR-5 Mod 1. The propeller is identical with that of the AIR-5 except that, because the fuze has no fixed propeller guard to interfere with the wind stream, the propeller is made less efficient by bending the vanes to an angle of 78° .

2. PROPELLER GUARD:

a. AIR-5. The guard is fixed to the fuze body; it consists of a short length of tubing with holes punched in the wall to allow the wind to flow past the propeller.

b. AIR-5 Mod 1. The guard is a removable cap taped to the flange of the fuze body and is removed after assembly of the fuze in the round. It is identical with the guard used on the AIR-7 (Mk 148). It seals the opening in the fuze body against moisture during shipping and handling.

3. SAFETY WIRE:

a. AIR-5. The safety wire clips over the propeller guard as in the AIR-2.

b. AIR-5 Mod 1. The end of the safety wire is wrapped around the fuze body, inside the removable guard.

4. A BURSTER ADAPTER screwed into the base of the fuze body in place of a magazine, contains 0.625-in. diameter threads into which a standard tetryl-loaded burster tube is screwed.

The propeller setting of both AIR-5 fuzes requires two complete turns (four ratchet stops) during acceleration of the rocket for the firing pin to advance sufficiently to prevent re-engagement of the propeller-locking pin with the stops on the propeller hub.

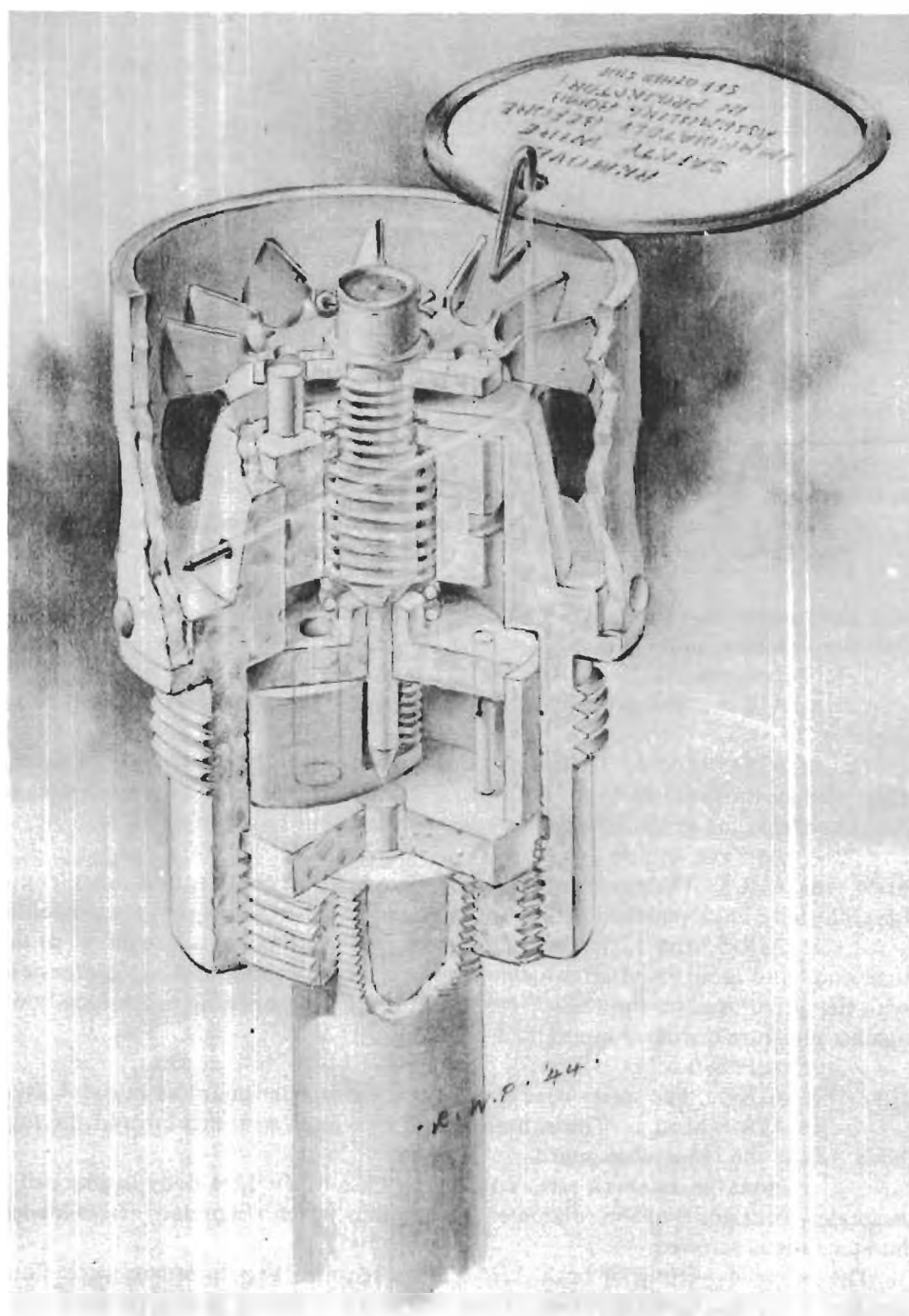


FIG. 15. AIR-5 fuze as shipped, unarmed, with burster tube attached (Nose Fuze Mk 147).

2.053. **ARMING AND FIRING.**—The arming and firing characteristics of the AIR-5 fuzes in the 7.2-in. CWR are similar to those of the AIR-2 in the 4.5-in. Barrage Rocket.

2.054. **REMARKS.**—Twenty-five hundred AIR-5 (Mk 147) and 2500 AIR-5 Mod 1 (Mk 147 Mod 1) fuzes were manufactured by CIT for delivery to the Army Chemical Warfare Service for extensive tests in the 7.2-in. Chemical Rocket. On the basis of these tests it was decided that the AIR-5 Mod 1 was preferable, and this was adopted for standardization of the rocket.

2.06. AIR-6 FUZE

Rocket in which used

Fast-burning, short-range 4.5-in. Barrage Rocket

Dimensions and weight

Over-all length: 4.2 in.

Thread: 1.5"-12NF-2

Weight: 1.2 lb

Material

Same as Mk 137 except molded bakelite propeller

Explosive components

Same as for Mk 137

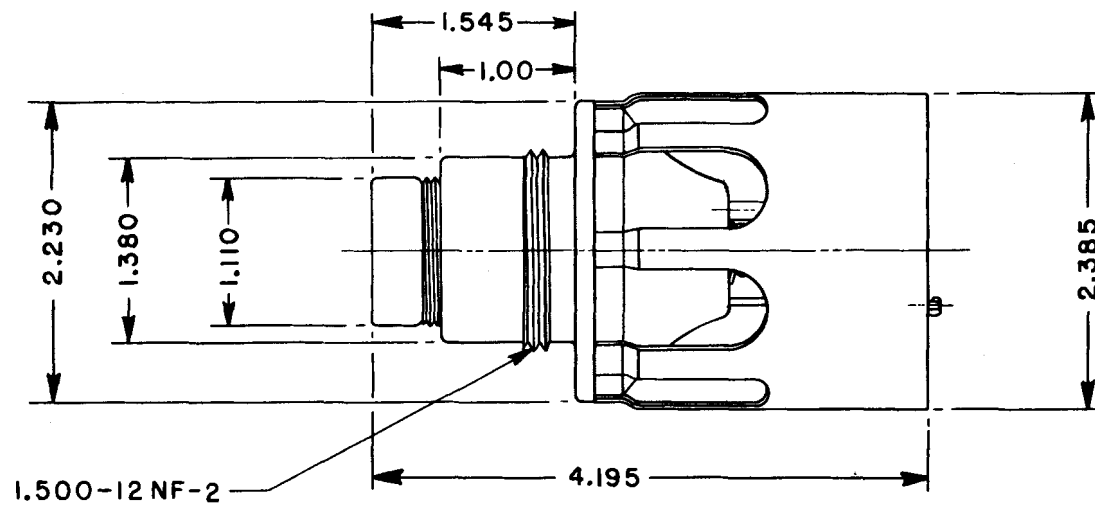
General arrangement drawing

CIT Drawing No. C1-01

2.061. GENERAL.—The AIR-6 fuze was originally developed for use in the fast-burning short-range 4.5-in. Barrage Rocket. This rocket was devised for short-range (250 yd) countermining work. The charge proved too small for effective use in this application and the projectile was not standardized for production. However, the fuze development was continued from time to time as fuze requirements for rockets with general characteristics (fast burning, low velocity) similar to those of the short-range barrage rocket arose. None of these was carried through to standardization for service use, but they led to development of the fuze to the point where the design is ready for standardization, should the need for this type of fuze again arise.

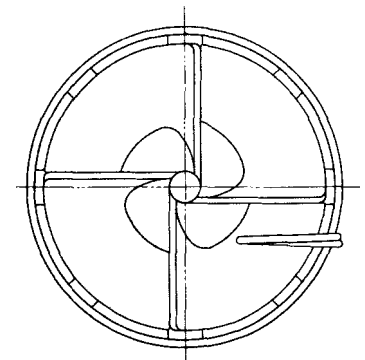
The characteristics of the fast-burning short-range 4.5-in. Barrage Rocket which determined the special features of the AIR-6 fuze were its short burning time and low velocity.¹ The short burning time required that the propeller, which must make the number of turns necessary to prevent re-engagement with the vane-locking pin during the burning time, be extremely efficient. The low velocity required that the fuze be unusually sensitive, in order to insure firing on soft targets and water at low striking velocity. The AIR-2 (Mk 137) fuze, designed to arm and fire in the standard 4.5-in. Barrage Rocket with more than twice the burning time and velocity of the short-range rocket, was unsuitable. In the AIR-6 fuze the rate of arming and the sensitivity of firing have been extended to the limits which appear to be practicable in the AIR type of fuze. Use of a "funnel" in front of the propeller guard to increase the amount and velocity of air flowing past the propeller might enable the fuze to arm at a slightly lower velocity. Such a cone of approximately 4 in. diameter with a 60° included angle has been found to have some effect. However, it is doubtful whether the fuze will fire at lower impact velocity, in good part because rockets of such low velocity have considerable yaw that is not damped out after the short air travel involved. For this reason the velocity of a round at impact is apt to make a considerable angle (as large as 20° or 30°) with the axis of the round, with resulting large side forces. These forces

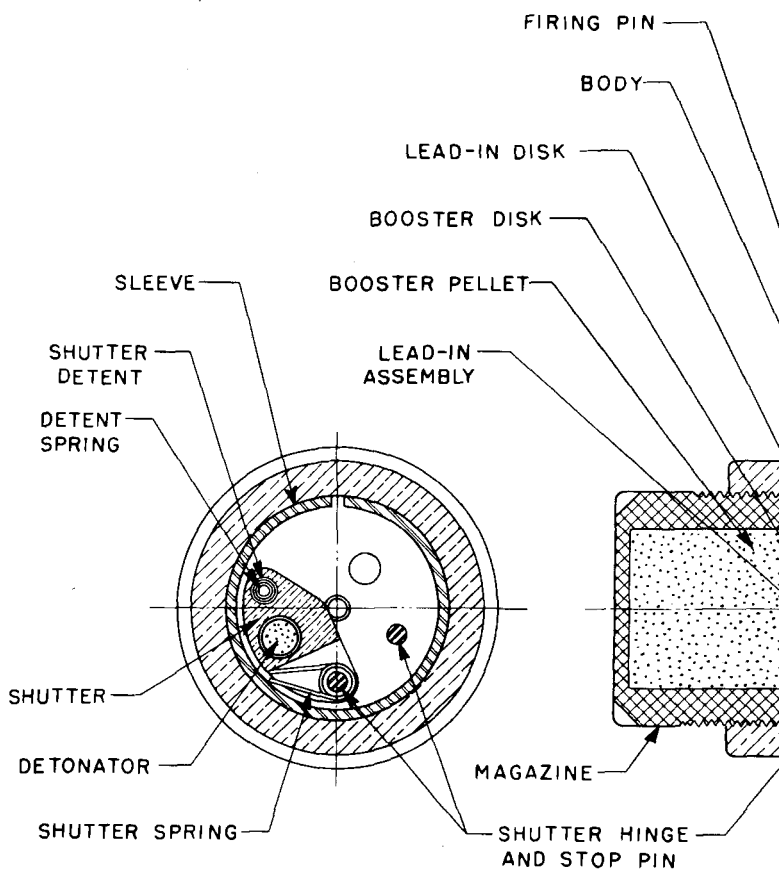
¹ For data see Table I, Ch. I.



(ALL DIMENSIONS ARE MAX.)

FIG. 16. Outline view of AIR-6 fuze.





SECTION A-A

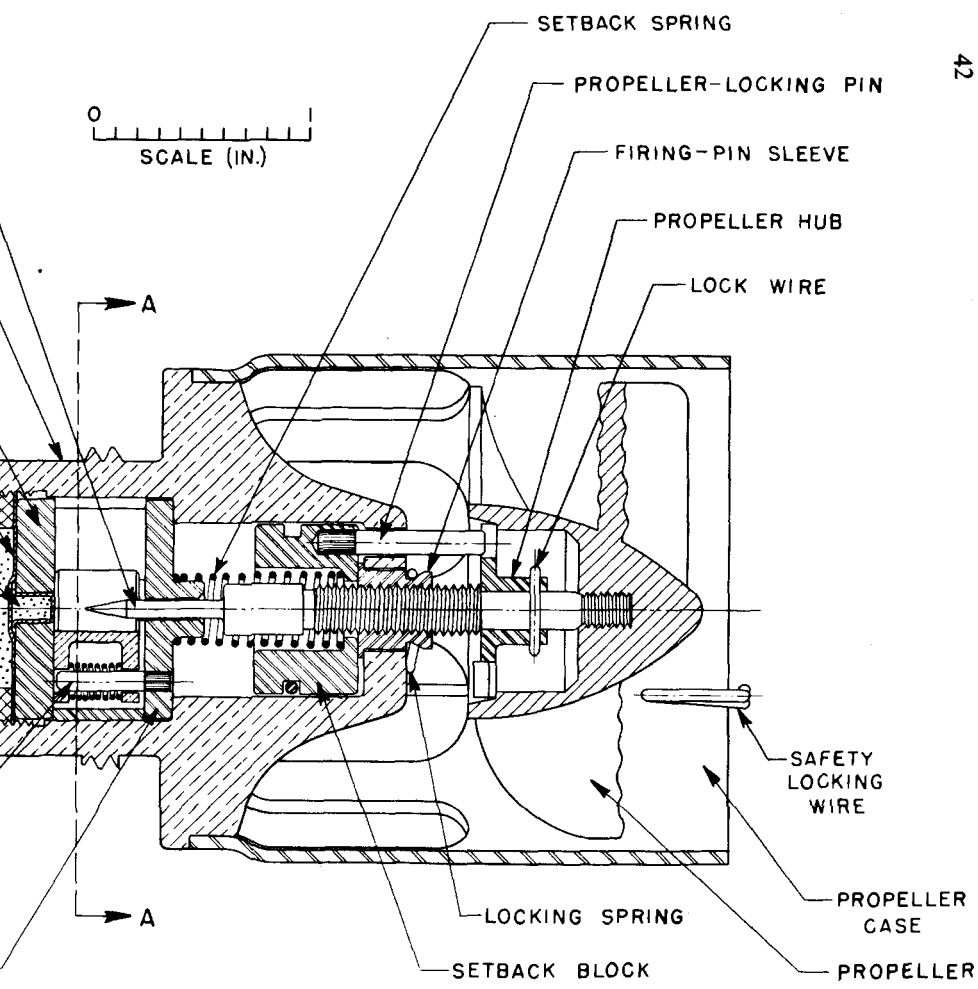


FIG. 17. AIR-6 fuze, unarmed.

may bend the firing pin over, or even tear the fuze out of the head without the firing pin's being moved back far enough to strike the primer.

2.062. DESCRIPTION.—The method of operation of the AIR-6 fuze is similar to that for the AIR-2 (Mk 137), and a number of the parts are identical. The differences in design and operation are associated with the unusually short burning time and low velocity of the rocket for which the AIR-6 fuze was developed. The AIR-6 fuze differs from the AIR-2 fuze in the following respects:

1. The propeller is of molded bakelite, is very light in weight, and has curved vanes for maximum efficiency, in order that the fuze may arm at high motor temperatures. Arming at high temperature requires that within about 0.1 sec after the round is launched the propeller must rotate the firing pin the one to one and one-half turns required to prevent re-engagement of the vane-locking pin. The propeller guard is designed to fit the bakelite propeller, guiding the wind stream through it with a minimum of resistance.

2. To permit closer setting of the propeller-firing-pin assembly the hub of the AIR-6 fuze has four instead of two ratchet stops for the vane-locking pin.

3. The total distance the setback block is retracted by acceleration of the rocket is twice that in the AIR-2 fuze. This gives the propeller-firing-pin assembly an additional short time interval to turn and escape re-engagement of the propeller-locking pin with a stop on the propeller hub while the setback block is returning to its forward position.

4. To provide the firing sensitivity required on low-velocity impacts it was necessary to abandon the method of firing which involved shearing of the body threads by the firing pin. Instead, the firing pin is screwed into a bushing which in turn fits loosely in a hole in the nose of the fuze body. The bushing, or firing-pin sleeve, is held in place and prevented from turning by a flange on the end of the sleeve inside the fuze body and by a clip formed of phosphor-bronze spring wire; this clip fits in a groove around the portion of the sleeve extending from the nose of the body, and bears against the nose of the body, thus effectively clamping the sleeve to the nose of the body.

5. In order to accommodate the above design changes it was necessary to replace the AIR-2 fuze body with one adapted to these features.

2.063. ARMING.—The arming operation of the AIR-6 fuze is similar to that of the AIR-2 (Mk 137). One to one and one-half turns of the propeller-firing-pin assembly during acceleration of the rocket are required to prevent re-engagement of the propeller-locking pin; approximately eight turns are required to arm the fuze. Unlike the firing pin of the AIR-2, that of the AIR-6 does not rotate freely, but stops at the end of its travel when the unthreaded portion jams against the bushing.

2.064. FIRING.—The AIR-6 fuze is fired on impact with ground or water. The firing pin and bushing are driven back, expanding the locking spring, and the firing pin stabs the detonator primer, initiating the instantaneous explosive train. As compared with the other AIR fuzes the AIR-6 is extremely sensitive. A static force of only 15 lb is required to expand the locking spring and force the firing pin into the primer, as compared with 200 to 300 lb required to shear the threads in other fuzes of the AIR type.

2.065. REMARKS.—Since the fast-burning, short-range 4.5-in. Barrage Rocket was not standardized, the AIR-6 fuze was not standardized for production. However, 1200 AIR-6 fuzes were manufactured and loaded by CIT and delivered to the Army Ordnance Department in June, 1944, for tests in a demolition rocket consisting of a 100-lb head attached to the T22 rocket motor. The burning time and velocity of this rocket were comparable to those of the BR for which the fuze was originally designed.

2.07. AIR-7 (Mk 148) FUZE

Rockets in which used

3.5-in. Aircraft Rocket, with 3.25-in. Motor Mk 7 and 3.5-in. Head Mk 3, 5, or 9

5.0-in. Aircraft Rocket, with 3.25-in. Motor Mk 7 and 5.0-in. Head Mk 1

Dimensions and weight

Over-all length: 2.96 in.

Thread: 1.5"-12NF-2 on fuze body

1.7"-14NS-2 on adapter

Weight (with adapter): 1.6 lb

Material

Same as for Mk 137

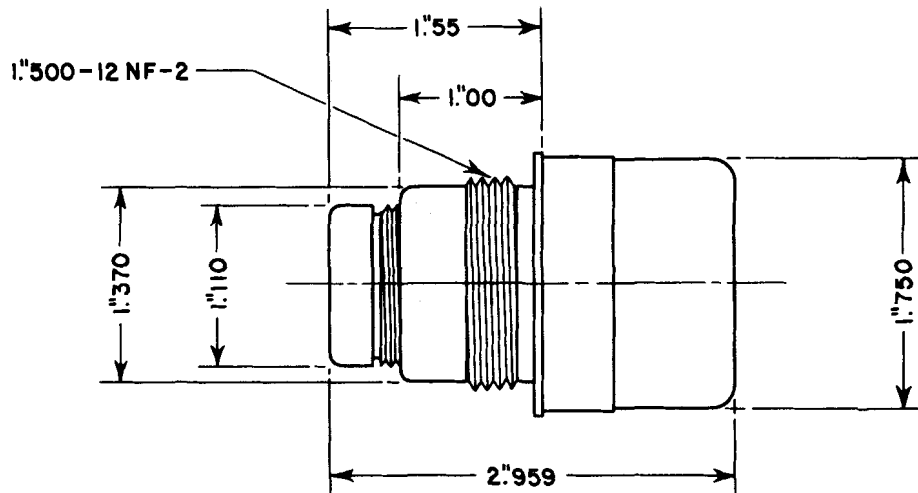
Explosive components

Same as for Mk 137

General arrangement drawing

BuOrd Drawing No. 394786

2.071. GENERAL.—When the 5.0-in. Aircraft Rocket was developed the need arose for a selective-arming point-detonating nose fuze to be used in this rocket in conjunction with a base fuze. The projectile was to be capable of being launched with the nose fuze *safe* when desired, in order to secure penetration of the target and functioning of the base fuze. The rounds were to be assembled with nose fuze, and were to be launched with the superquick nose fuze armed for functioning



(ALL DIMENSIONS ARE MAXIMUM)

FIG. 18. Outline view of AIR-7 fuze (Nose Fuze Mk 148).

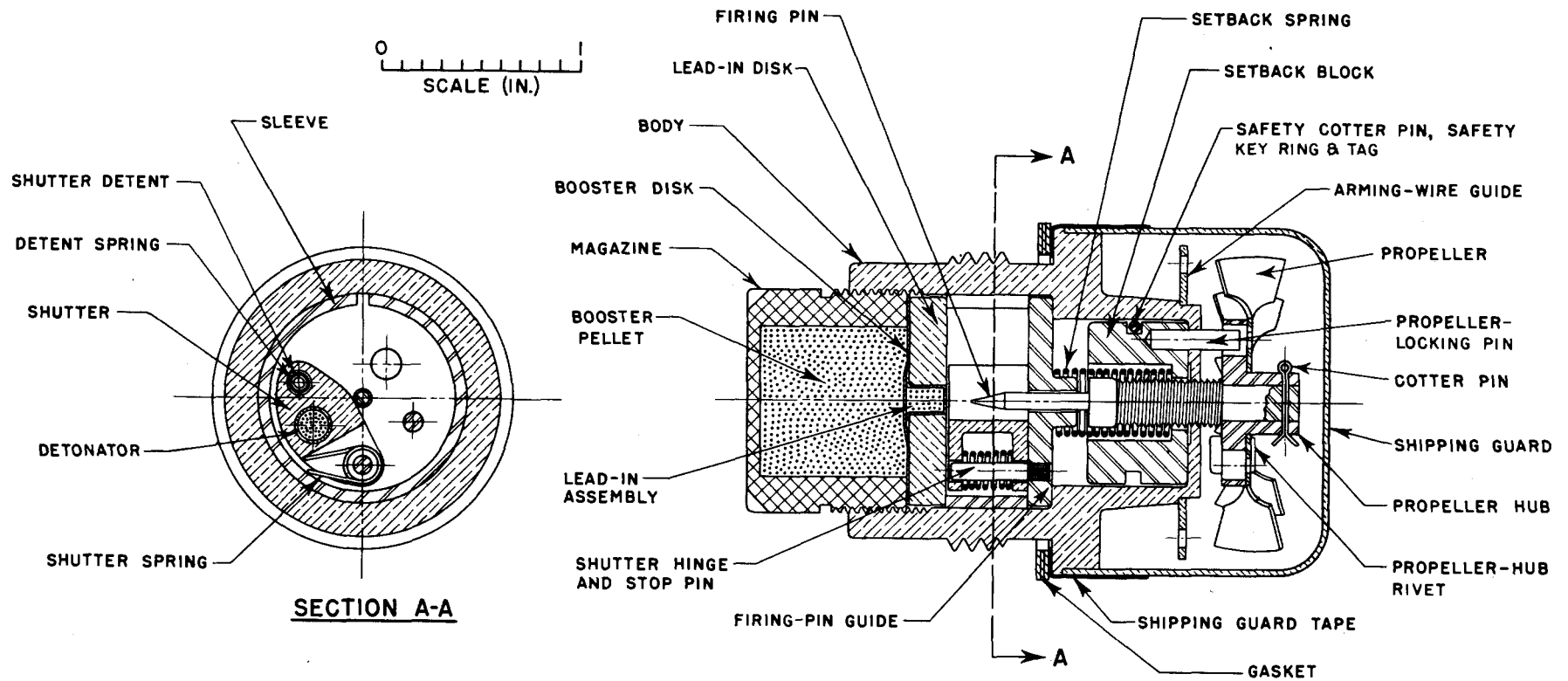


FIG. 19. AIR-7 fuze, unarmed.

against targets where detonation on the surface of the target is desired, as in strafing attacks.

The fact that the rounds would be launched from aircraft and assembled and loaded on launchers aboard aircraft carriers introduced new safety requirements. The principal desire (although not attained with the AIR-7) was that the minimum arming distance for rounds launched from stationary launchers should be 400 ft. It was also desired that the fuze arm in rockets fired from stationary launchers or from flying aircraft, in the latter case after traveling a considerable distance from the airplane.

Time was not available for the development of a fuze designed specifically for the aircraft rockets. The NIR fuze (Ch. 4), which was under development for aircraft rockets, had been shown to be unsuitable for use with the 5.0-in. AR because of the low velocity of this rocket. It was therefore decided, as an interim measure, to adapt the AIR-2 (Mk 137) fuze to the aircraft rocket by making changes only where necessary to meet the requirements for an aircraft rocket fuze; thus procurement would be greatly facilitated, since the Mk 137 fuze was already in quantity production. The AIR-7 (Mk 148) is the fuze which was developed from the AIR-2 (Mk 137).

2.072. DESCRIPTION.—The AIR-7 fuze is a modification of the Mk 137 fuze, the principle of operation and the majority of parts being identical. The differences are associated with the adaptation of the AIR-7 to the 5.0-in. AR and may be described as follows:

1. In order to increase the arming distance so that the fuze would arm at the maximum distance practicable with this type of fuze a small heavy propeller with vanes bent to 85° was used. This was possible because of the much greater burning time and velocity of the 5.0-in. AR as compared with the 4.5-in. BR (Table 1, Chapter 1).

2. Because of the relatively great burning time and velocity of the 5.0-in. AR it was possible to increase the number of turns of the propeller-firing-pin assembly required during burning to prevent re-engagement of the vane-locking pin. The setting was increased to 3 or 4 turns by increasing the thickness of the hub and using rivet-head stops which projected 0.062 in. from the hub.

3. In order to make the fuze selective-arming, that is, to enable the round to be fired with the fuze either *safe* or *armed* at the pilot's discretion, and also to provide additional safety against arming on the launcher, an arming wire of the type used with bomb fuzes was adapted to the fuze. This arming wire was attached to an arming-wire release latch on the aircraft, which holds the arming wire and withdraws it from the fuze when the round is fired. The free end of the arming wire passes through a hole in an arming-wire guide attached to the fuze body directly beneath the propeller and between two of the propeller vanes. On the end of the arming wire are placed two 3-lb Fahnestock clips,¹ between which and the arming-wire guide is a piece of brass tubing 4 in. long. This tubing was found to be necessary² to prevent the clips from damaging or fouling the propeller

¹ By a "3-lb" clip is meant that it requires a force of three pounds to move the clip along the wire.

² CIT/PMC 2.15, 16 January 1944, Part 2, p. 2.

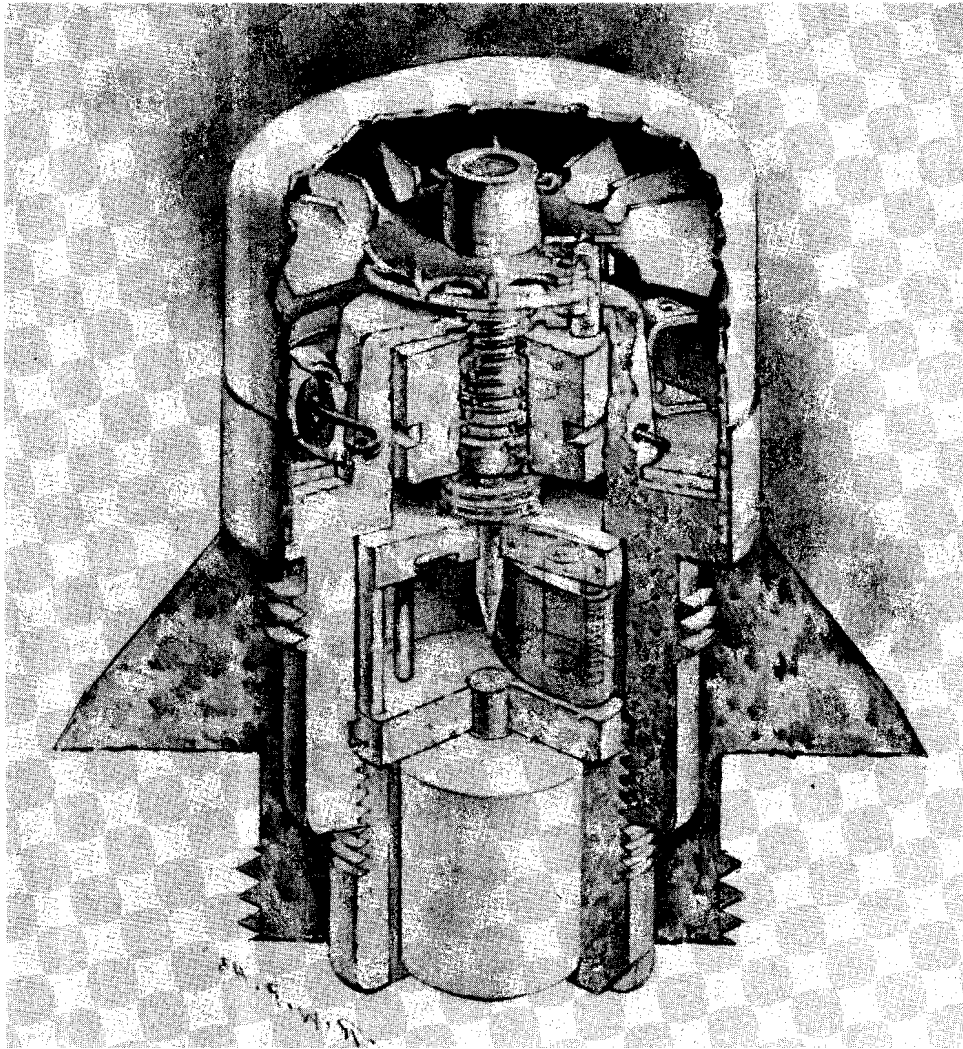


FIG. 20. AIR-7 fuze as shipped in adapter (Nose Fuze Mk 148).

when the wire was pulled. If it is desired to launch a round with the nose fuze *armed* a solenoid is energized which locks the arming-wire release latch. If it is desired to launch a round with the fuze *safe* this solenoid is not energized, and thus the arming wire, held to the fuze by the Fahnestock clips, pulls free from the latch and remains on the fuze. The arming wire is installed after the round is loaded on the launcher.

4. To give the fuze a degree of protection against moisture before it is finally readied for use, a brass cup (shipping guard) is provided; this fits against a shoulder on the fuze body flange and covers the propeller and all unsealed openings into the fuze body. The cup is sealed by tape, which is not stripped off until it is necessary,

in readying the assembled round, to remove the cup and insert the arming wire. Under the cup is a safety wire, which locks the setback block; this wire is withdrawn after the arming wire is installed.

5. The end of the threads on the firing pin is not relieved as in the AIR-2 fuze, but is run out, so that the firing pin, after advancing to the end of the threads, jams against the nose plate of the fuze body and stops. This feature was found to be necessary, because if the propeller-and-firing-pin assembly is allowed to spin freely the spin velocity becomes so great in high-velocity rockets fired from aircraft that centrifugal force may break the firing pin.

6. In order to adapt the 1.5-in.-12NS threads of the Mk 137 fuze body (modified for the AIR-7) to the 1.7-in.-14NS threads of the fuze seat liner in the 5.0-in. Mk 1 Head the fuze is assembled in a special adapter and locked with a setscrew.

2.073. **ARMING.**—Before the rocket is fired, the shipping guard which protects the nose of the fuze is removed, the safety wire which locks the setback block withdrawn, an arming wire inserted through one of the arming-wire guides and through the propeller, and the arming-wire sleeve and clips assembled. When the round is fired the sequence of operations is as follows: The setback pellet is retracted until the propeller-locking pin is flush with or slightly below the front face of the fuze body. The arming wire is pulled out, freeing the propeller assembly, which then starts to turn. The wind stream rotates the propeller assembly, thus advancing the attached firing pin forward on the ring-pin thread (left-hand thread). The propeller must make from 3 to 4 turns during acceleration in order to unscrew the firing pin sufficiently to prevent re-engagement of the propeller-locking pin with the propeller at the end of acceleration. After 8 to 10 turns of the propeller, the

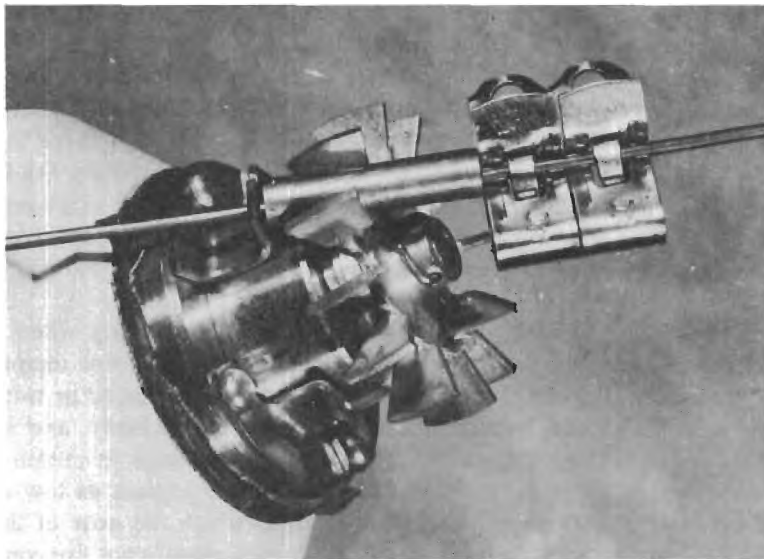


FIG. 21. AIR-7 fuze shown readied with arming wire, arming wire sleeve, and two Fahnestock clips in place.

firing pin has moved far enough to free the detonator shutter. The latter is then rotated by the shutter spring into the *armed* position (detonator in line with the firing pin and lead-in) and is held there by a detent. After 1 to 2 additional turns the end of the firing pin thread is reached, and the firing pin stops turning.

Arming distances are variable for two reasons: first, in aircraft firing the initial air velocity increases the torque on the propeller and thus reduces the arming distance; second, the friction between the shutter and the lead-in disk becomes great enough at a setback of about 40 g to prevent rotation of the shutter even after the firing pin is clear. The latter factor depends to a considerable extent on the smoothness of the surfaces involved. Because of this friction, arming is often not completed until burning is over. When the friction effect is not operative, the arming distance for aircraft firing is roughly independent of the acceleration of the round, and hence independent of the powder temperature and the difference in weights of the 3.5-in. and the 5.0-in. AR.

Measured approximate arming distances (in 5.0-in. AR) can be summarized as follows:

AIRPLANE SPEED (knots)	MINIMUM ARMING DISTANCE MEASURED FROM AIRPLANE (ft)
0	300
150	150
200	125
350	20

The above values will be attained only when the frictional forces on the shutter described in the preceding paragraph are insufficient to cause delay in the shutter action. If these forces are large enough to restrain the shutter, arming will be delayed until burning of the propellant in the rocket motor is completed. The burning distances for the 3.5-in. and 5.0-in. AR with the 3.25-in. Mk 7 motor vary with the temperature. At 0°F the distances are about 800 ft for the 3.5-in. AR and 530 ft for the 5.0-in. AR. At 130°F they are about 320 ft and 195 ft for the 3.5-in. and 5.0-in. AR, respectively. It should be noted that these distances are for land-fired projectiles, but will also correspond to distances from the airplane for aircraft-fired projectiles. For aircraft firing the distance from the point at which the round is fired to the point where burning ends will be equal to the burning distance plus the distance the airplane travels during the burning time.

Tests indicate that the Mk 148 fuze will not arm consistently when ground-fired in the 5.0-in. AR with the 3.25-in. Mk 7 motor at high motor temperatures.

2.074. **FIRING.**—The AIR-7 fuze is fired at impact with ground or water when the firing pin is driven back, shears the threads in the fuze body, and stabs the primer of the instantaneous detonator. The fuze is fast enough to obtain effective fragmentation above ground. It functions at angles of impact as low as 5° on water and on targets (soft ground for example) into which the nose of the round penetrates. On hard targets (steel plate) the fuze will probably not fire consistently at angles less than 20° to 25°.

2.075. **REMARKS.**—Approximately 5000 AIR-7 (Mk 148) fuzes were manufac-

tured and loaded for the Navy by CIT, and delivered in late 1943. In addition, 25,000 sets of parts peculiar to the Mk 148 were delivered to Navy contractors manufacturing the Mk 137 fuze; these parts were for assembly with parts from the Mk 137 to make Mk 148 fuzes.

While the AIR-7 fuze was adopted as a temporary expedient for service use, pending the development and production of a fuze (AIR-8) designed specifically for use in aircraft rockets, it was recognized that the fuze had many shortcomings. The chief of these are stated below:

1. After removal of the protecting cup the fuze is not waterproof, and consequently fuzes from unfired rounds returned from flights probably could not be used again.

2. Difficulties associated with assembly of the arming wire and use of the arming-wire sleeve and clips resulted in duds unless careful installation was made.

3. The design does not offer good support for the firing pin against side forces, and consequently on low-angle impacts on hard surfaces the firing pin tends to break off rather than be driven into the detonator. Since low-angle attacks with aircraft rockets are common, this feature was objectionable.

The Mk 148 fuze was replaced in service by the Mk 149 (AIR-8).

2.08. AIR-8 (Mk 149) FUZE

Rockets in which used

3.5-in. Aircraft Rocket, with 3.25-in. Motor Mk 7 and 3.5-in. Head Mk 3 or Mk 5

5.0-in. Aircraft Rocket, with 3.25-in. Motor Mk 7 and 5.0-in. Head Mk 1

5.0-in. High-Velocity Aircraft Rocket, with 5.0-in. Motor Mk 1 and 5.0-in. Head Mk 6

Dimensions and weight

Over-all length: 3.34 in.

Thread: 1.7"-14NS-2

Weight: 2.6 lb

Material

Body: steel

Nose plate: brass

Firing pin: steel

Cup and clamp: steel

Firing-pin guide: steel

Magazine: zinc alloy

Explosive components

Same as for Mk 137

General arrangement drawing

BuOrd Drawing No. 393783

2.081. GENERAL.—The AIR-8 (Mk 149) fuze is similar in general operational principles to the AIR-2 (Mk 137), but designed specifically for use as a nose fuze for aircraft rockets. The requirements were the same as those for the AIR-7 (Mk 148), but in the design of the AIR-8 an effort was made to correct the shortcomings inherent in the Mk 148 which were well known at the time the development of the AIR-8 was started. It was desired to retain the fundamental operating principles of the AIR type of fuze, since these were well explored, but no attempt was made to utilize parts from other AIR fuzes for the sake of facilitating production, unless these parts were readily adaptable. As a consequence the only Mk 137 parts utilized are the explosive components and some of the metal parts (shutter, lead-in disk, etc.) associated with them.

Following are the principal design features of the Mk 149 that distinguish it from earlier AIR type fuzes:

1. Complete moistureproofing is provided by a cap-and-clamp assembly covering the nose of the fuze and all the body openings. The cap-and-clamp assembly is similar in general to that developed earlier for the SIR (Mk 139) fuze.

2. A second setback block, containing a pin which locks the shutter in the *safe* position during acceleration of the rocket, is added. The purpose of this feature is to provide, under all conditions of firing, a positive arming delay at least until burning of the rocket motor is complete.

2.082. DESCRIPTION.—In the *unarmed* position the firing pin is screwed down alongside the detonator shutter, holding the latter to one side. In this position the

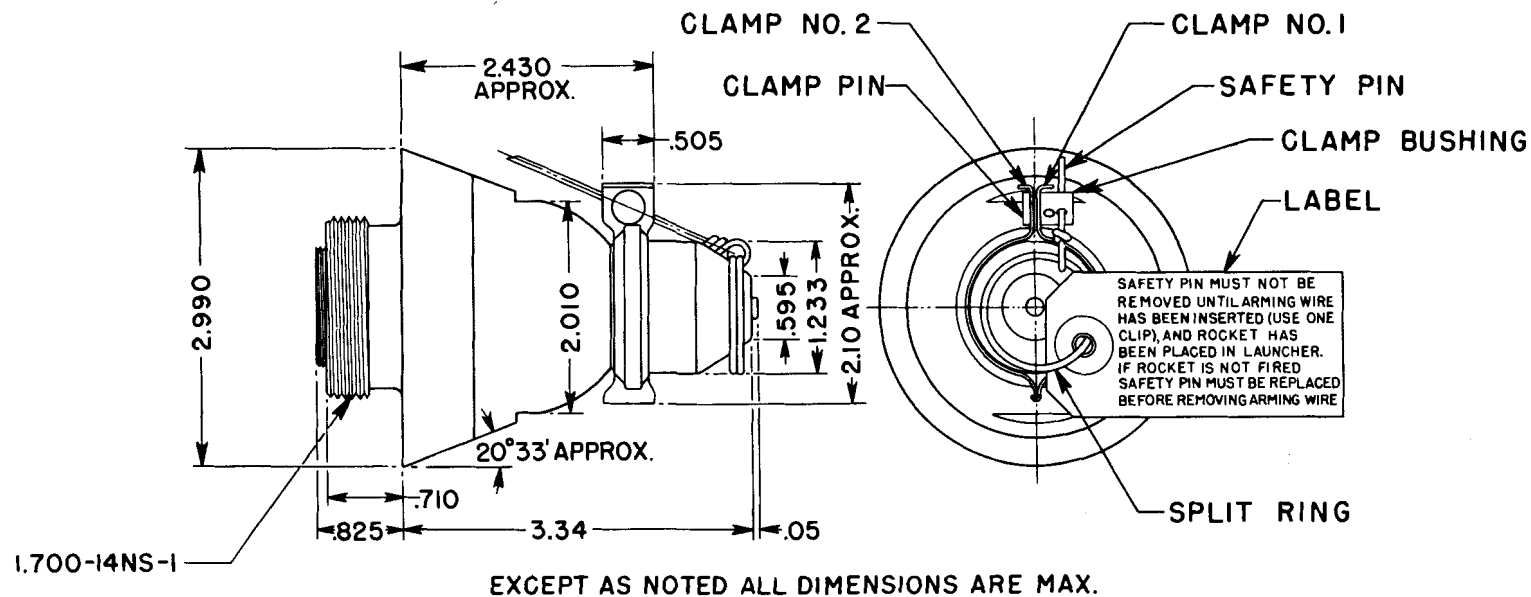


FIG. 22. Outline view of AIR-8 fuze (Nose Fuze Mk 149).

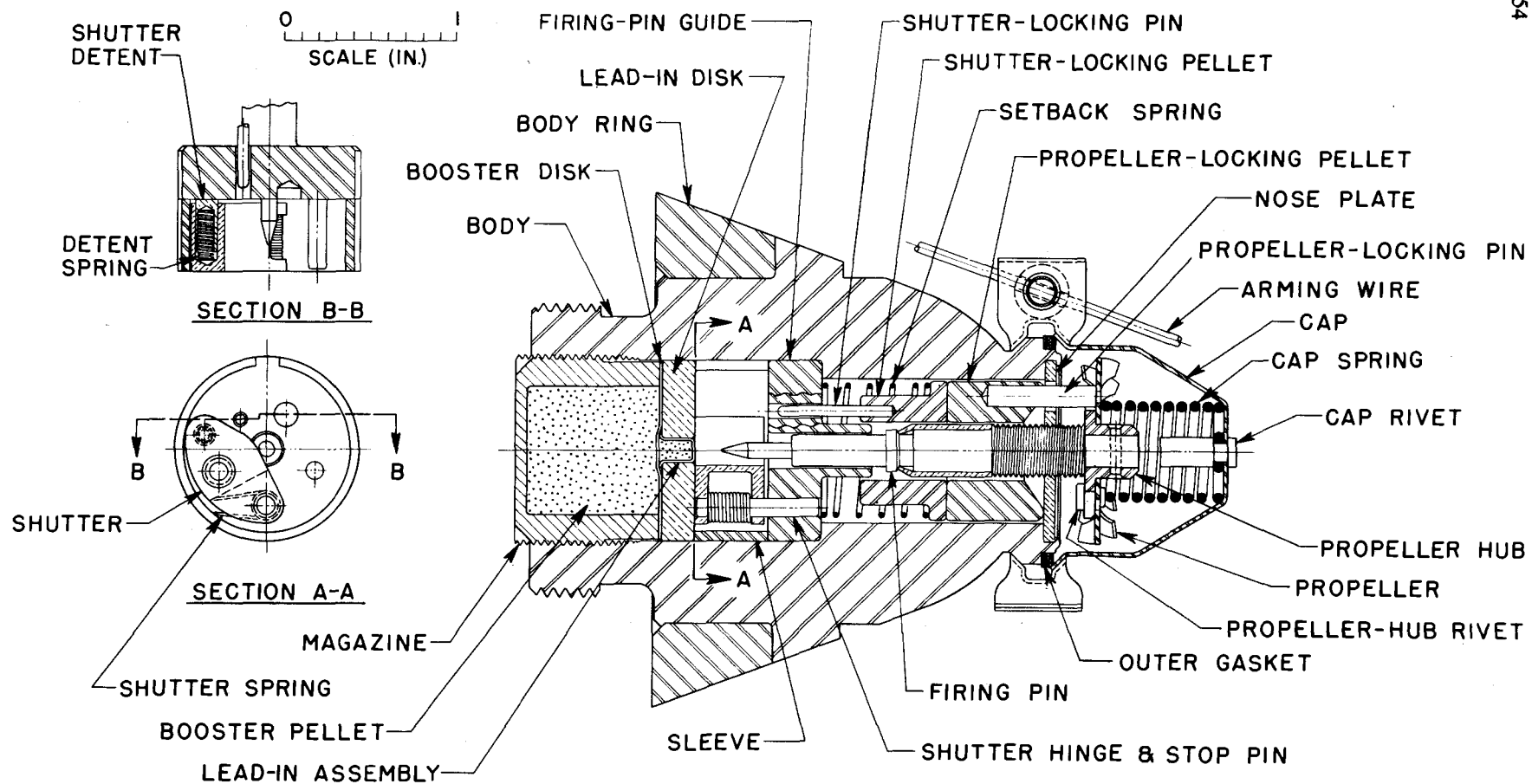


FIG. 23. AIR-8 fuze, unarmed.

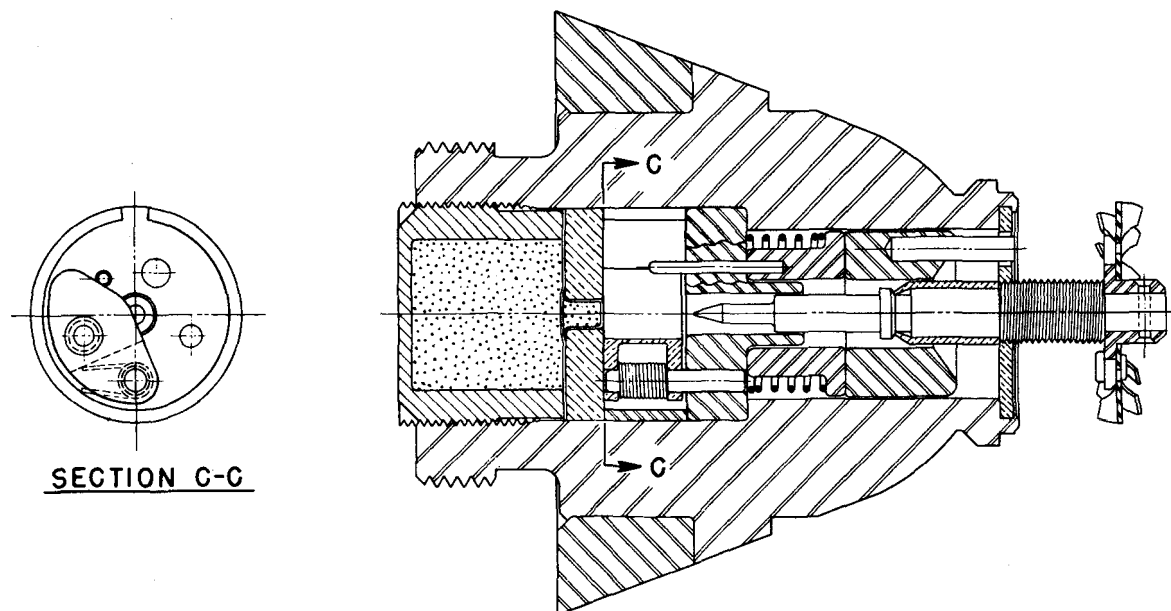
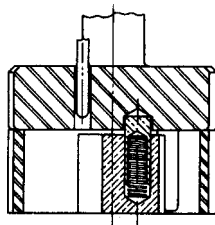
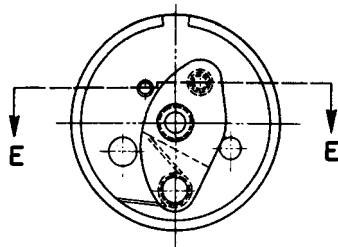


FIG. 24. AIR-8 fuze, showing motion of parts during burning of rocket motor.



SECTION E-E



SECTION D-D

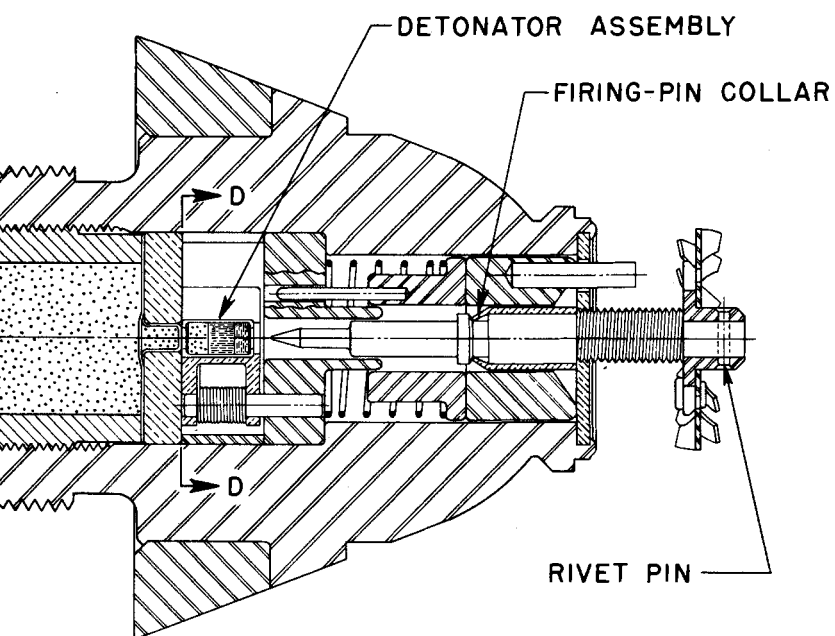


FIG. 25. AIR-8 fuze, armed.

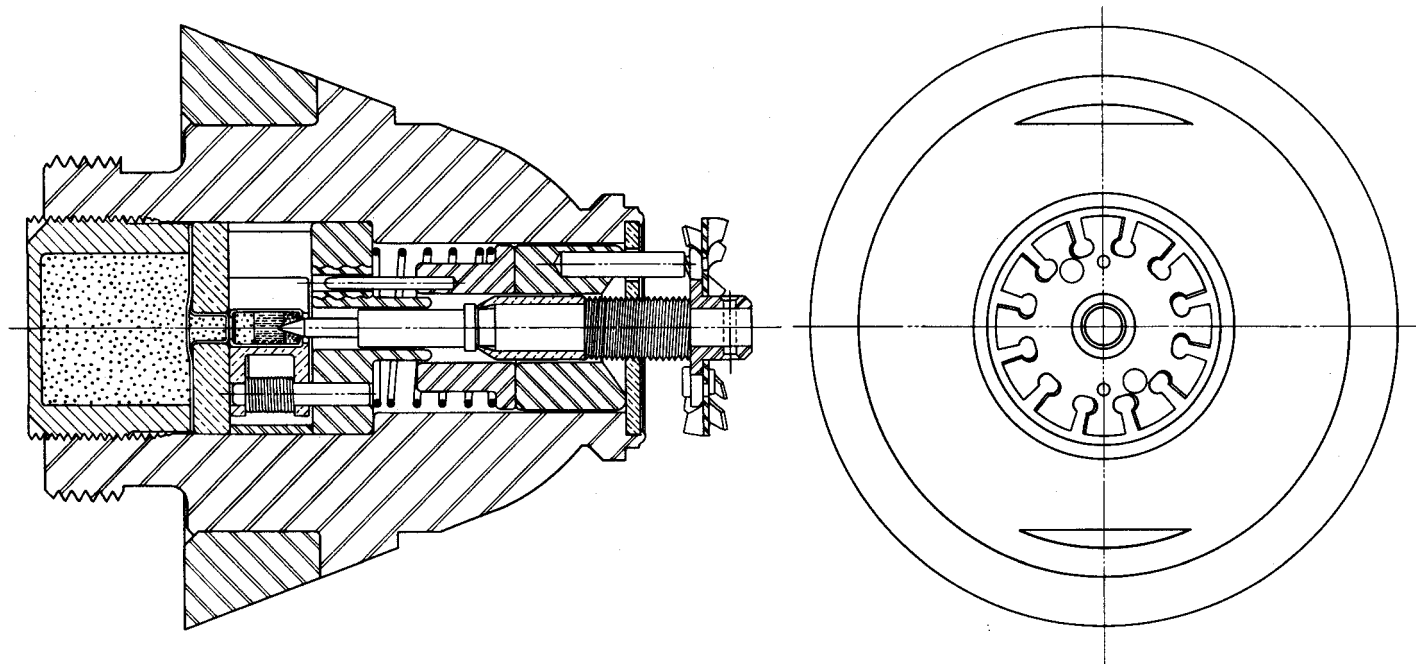


FIG. 26. AIR-8 fuze, fired, and end view.

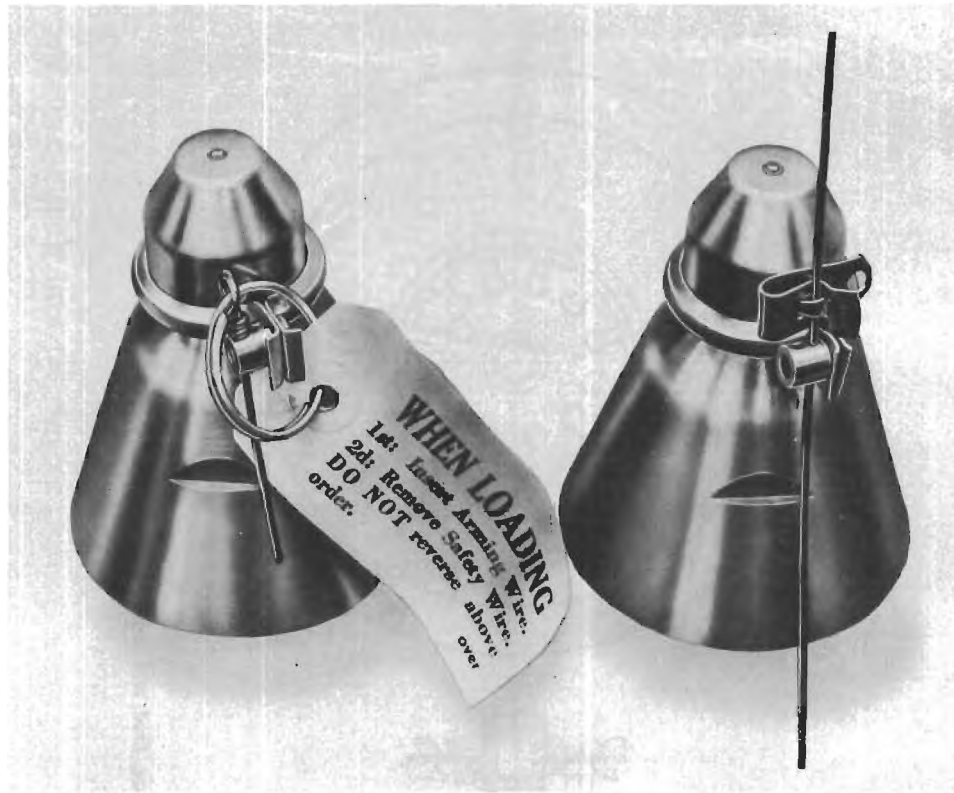


FIG. 27. AIR-8 fuze; *left*, as shipped; *right*, as assembled in round (Nose Fuze Mk 149).

fuze is detonator-safe. The propeller is prevented from turning by the propeller-locking pin attached to the propeller-locking pellet. The cap on the nose of the fuze is held tightly in place on the gasket by a clamp assembly held together by the safety wire. This cap seals the working parts in the nose of the fuze against moisture and is removed only when released by the arming wire when the projectile is fired. The cap spring bears on the top of the propeller, preventing it from turning.

When an assembled round is loaded in the launcher a bomb-release arming wire is inserted in a hole next to the safety wire in the clamp-pin and bushing assembly, and one Fahnestock clip is placed on the end of the arming wire. The safety wire is then removed.

2.083. **ARMING.**—When the round is fired the arming wire pulls free, releasing the clamp assembly, which flies apart. The strong cap spring throws off the cap, exposing the propeller. At the same time acceleration retracts the propeller-locking pellet, releasing the propeller, and the shutter-locking pin attached to the shutter-locking pellet protrudes from the face of the firing-pin guide along the side of the shutter. As the propeller turns, the firing pin advances, finally freeing the detonator shutter. In order to clear the propeller-locking pin, between 2 and

2.5 turns of the propeller are required during acceleration to prevent re-engagement of the propeller-locking pin and the propeller hub rivets, which act as stops. About 8 turns are necessary for the point of the firing pin to free the shutter. As long as acceleration continues the shutter is locked in the *safe* position by the shutter-locking pin. At the end of acceleration this locking pin is withdrawn by the setback spring and the shutter is permitted to swing into the *armed* position, provided the firing pin by this time has spun clear of the shutter. When released by both the firing pin and the locking pin the shutter is rotated into the *armed* position by the shutter spring, bringing the detonator into line with the firing pin and tetryl lead-in. The shutter is locked in the *armed* position by a detent. The firing pin jams and stops when the end of the threads reaches the nose plate.

Because of the locking of the shutter in the *safe* position by the shutter-locking pin during acceleration, arming will not occur until after the end of acceleration, whether or not the firing pin has spun free of the shutter before this occurs. Arming distances based on preliminary measurements appear to be slightly greater than the burning distances of the 3.5-in. AR and the 5.0-in. AR. Observations indicate a delay of about 0.1 sec after acceleration has ended. Therefore the arming

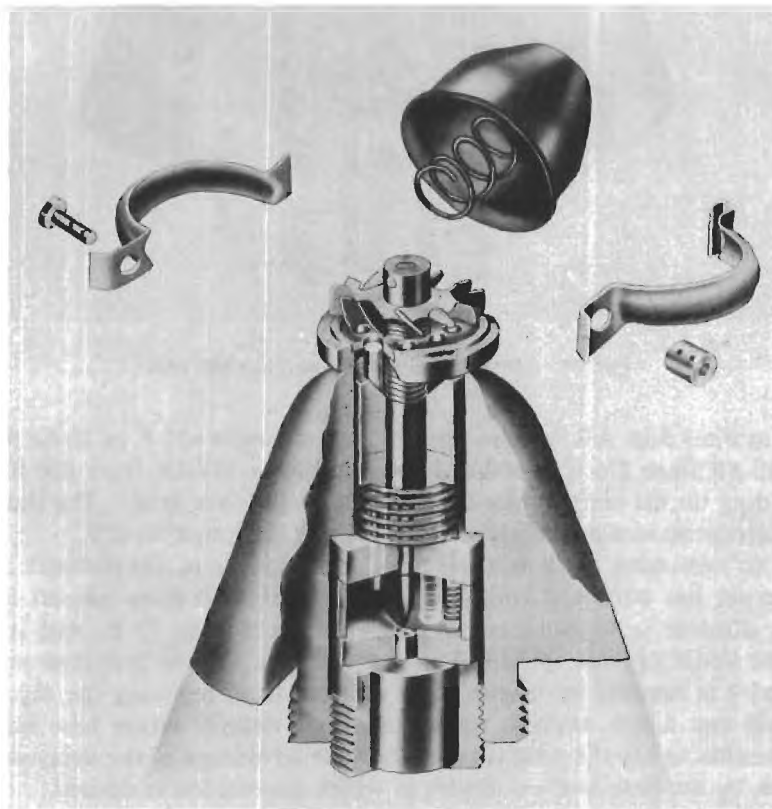


FIG. 28. AIR-8 fuze after the arming wire has released the clamp-bushing and protective cap. The fuze is still unarmed. (Nose Fuze Mk 149.)

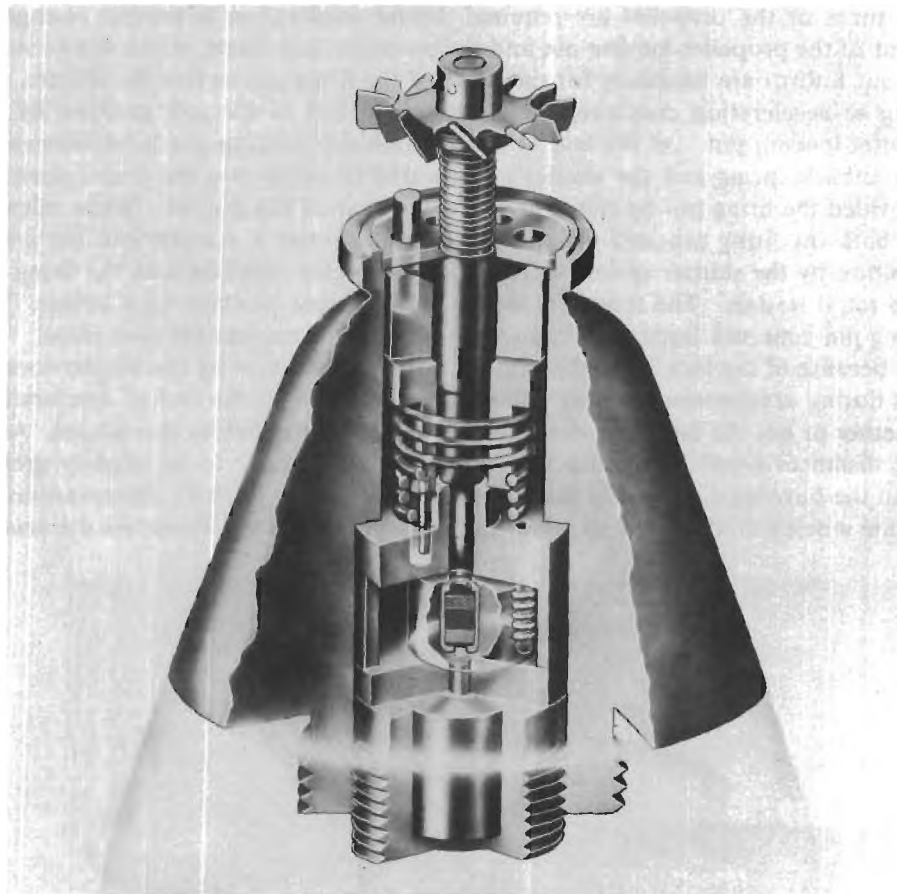


FIG. 29. AIR-8 fuze, armed (Nose Fuze Mk 149).

distance in the 3.5-in. AR will probably vary from about 425 ft to about 900 ft, in the 5.0-in. AR from 275 ft to 600 ft, and in the 5.0-in. HVAR from 650 ft to 1100 ft, depending on the temperature at which the rounds are fired.¹ The shorter distances correspond to a temperature of 130°F, and the longer to 0°F.

Tests to determine the partial arming distance, that is, the distance at which the firing pin has advanced completely, for rounds fired from aircraft indicated that this distance is variable, ranging from about 5 ft to 65 ft, and somewhat dependent upon airplane speed.² The Mk 149 fuze may be launched *safe* if the arming wire is released so that it stays with the fuze, retaining the cap. In the 5.0-in. AR and 5.0-in. HVAR, which also carry delayed-action base fuzes, it is often desirable to fire the nose fuze *safe* to take advantage of the delayed detonation given by the base fuze on targets in which penetration is desired.

¹ CIT/PMC 2.27, 9 April 1944, Part 2, pp. 6-7.

² CIT/PMC 2.27, 9 April 1944, Part 2, pp. 5, 6-7; PMC 2.34, 28 May 1944, Part 2, p. 18.

Because the Mk 149 fuze was originally designed for rounds launched from aircraft, its arming on the 5.0-in. AR fired from stationary launchers is not reliable at temperatures over about 100°F unless the cap is removed prior to firing.

2.084. **FIRING.**—Like the earlier AIR type fuzes, the Mk 149 fires instantaneously on impact when the firing pin is driven back, shears the threads in the nose plate, and stabs the primer of the detonator. It will function at very low angles of impact.

2.085. **REMARKS.**—Since the Mk 149 fuze was specifically designed for use in aircraft rockets, it has the following advantages over the Mk 148 in this application:

1. The waterproof cap assembly covering the propeller protects the working parts of the fuze from weather and icing until the round is actually fired.

2. The fuze body, of steel, is designed to fit directly into the fuze liner ring of the 3.5-in. and 5.0-in. aircraft rocket heads, and is more streamline. The body is also stronger, and therefore, when the nose fuze is launched *safe* to obtain the delayed action of the base fuze, it offers better protection to the nose of the rocket head.

3. A positive delay in arming until the end of acceleration is effected by the locking pin attached to the shutter-locking pellet. The minimum arming distance will be slightly greater than the burning distance of the rocket, whether the round is land- or airplane-fired.

4. The firing pin is stronger (larger diameter) and better supported than that of the Mk 148, so that there is a higher probability of firing on oblique impacts. The static force required to drive the firing pin into the detonator is less than in the Mk 148.

The development of the Mk 149 fuze was started in November, 1943, and between March and June, 1944, 45,000 fuzes of this type were manufactured and loaded by CIT for delivery to the Navy.

Preliminary tests of the Mk 149 fuze in the 11.75-in. Aircraft Rocket were made by NOTS, Inyokern, with satisfactory results. However, it should be pointed out that the same difficulties that appeared in connection with the AIR-12 fuze (see 2.12), when that fuze was launched *safe* in the 5.0-in. sphere-ogive head to obtain the delayed action of the Mk 166 (DDR) base fuze after water impact, would probably also arise under similar circumstances in the 11.75-in. AR with the Mk 149 and the Mk 162 (DDR) base fuze.

2.09. AIR-9 MOD 1 FUZE

Rockets in which used

- 5.0-in. High-Velocity Aircraft Rocket, with 5.0-in. Motor Mk 1 or Mk 2 and 5.0-in. Head Type Ex-1 (or CIT Model 31)
- 11.75-in. Aircraft Rocket, with 11.75-in. Motor Mk 1 or Mk 2, and 11.75-in. Head CIT Model 2 or Mk 4 (with adapter)

Dimensions and weight

- Over-all length: 5.65 in.
- Thread: 1.50"-12NF-2
- Weight: 2.5 lb

Material

- Nose: hardened steel SAE 4150
- Body: cold-rolled steel, AISI 1137
- Shutter: hardened steel SAE 4150
- Firing pin: hardened steel SAE 4150
- Magazine: cold-rolled steel, AISI 1137

Explosive components

- Nose detonator: from Bomb Fuze Mk 219, except loaded with lead azide
- Relay detonator: sensitive primer from Projectile Fuze Mk 20
- Delay-detonator assembly: from Nose Fuze Mk 145
- Lead-in: from Nose Fuze Mk 137
- Booster: AIR-9 (approximately 12 gm tetryl)

General arrangement drawing

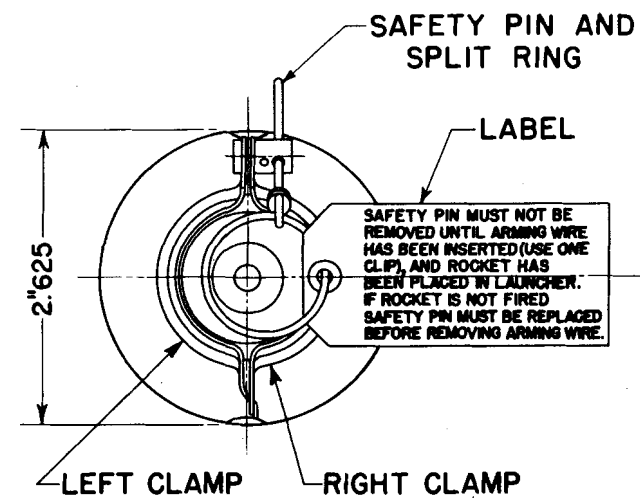
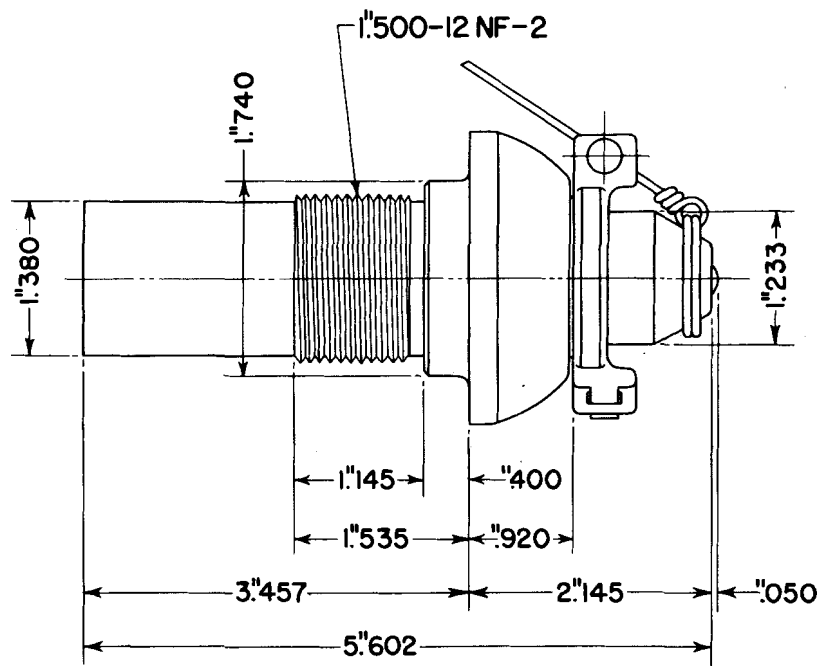
- CIT Drawing No. C9-01

2.091. GENERAL.—The AIR-9 Mod 1 is derived from the preceding AIR fuzes, especially the AIR-8, being a point-detonating fuze that arms in the same manner. It differs in two major details, in being water-discriminating, that is, in firing only on hard targets, and in containing a pyrotechnic delay.

The need for this fuze arose from the development of larger caliber aircraft rockets that had tactically useful underwater trajectories. Since weight limitations of the 3.5-in. AR require that any high-explosive content be small, the solid slug heads were used almost entirely. However, the 5.0-in. HVAR has enough capacity that loading with HE is desirable if the rocket can be satisfactorily fuzed.

These particular rockets have the unusual properties that when fired into water they lose velocity only comparatively slowly, and their path is predictable, being either a straight-line continuation of their air trajectory or a curve turned slightly upwards. Representative underwater velocities for two rockets in which the AIR-9 Mod 1 fuze may be used are listed in Table 1, Ch. 5. The usefulness of such rockets against floating targets of many types is apparent because of the large extension of target area that results. Extended discussions of the effective target area of various types of target have been included in two special reports.¹

¹ *Further Investigations of the Underwater Behavior of Aircraft Rockets*, CIT/JBC 27, (OSRD Report No. 2152), I. S. Bowen, 26 June 1944; *Underwater Behavior of the 11.75-in. Aircraft Rocket*, CIT/IPC 65, I. S. Bowen, 25 October 1944.



(DIMENSIONS GIVEN ARE MAX.)

FIG. 30. Outline view of AIR-9 Mod 1 fuze.

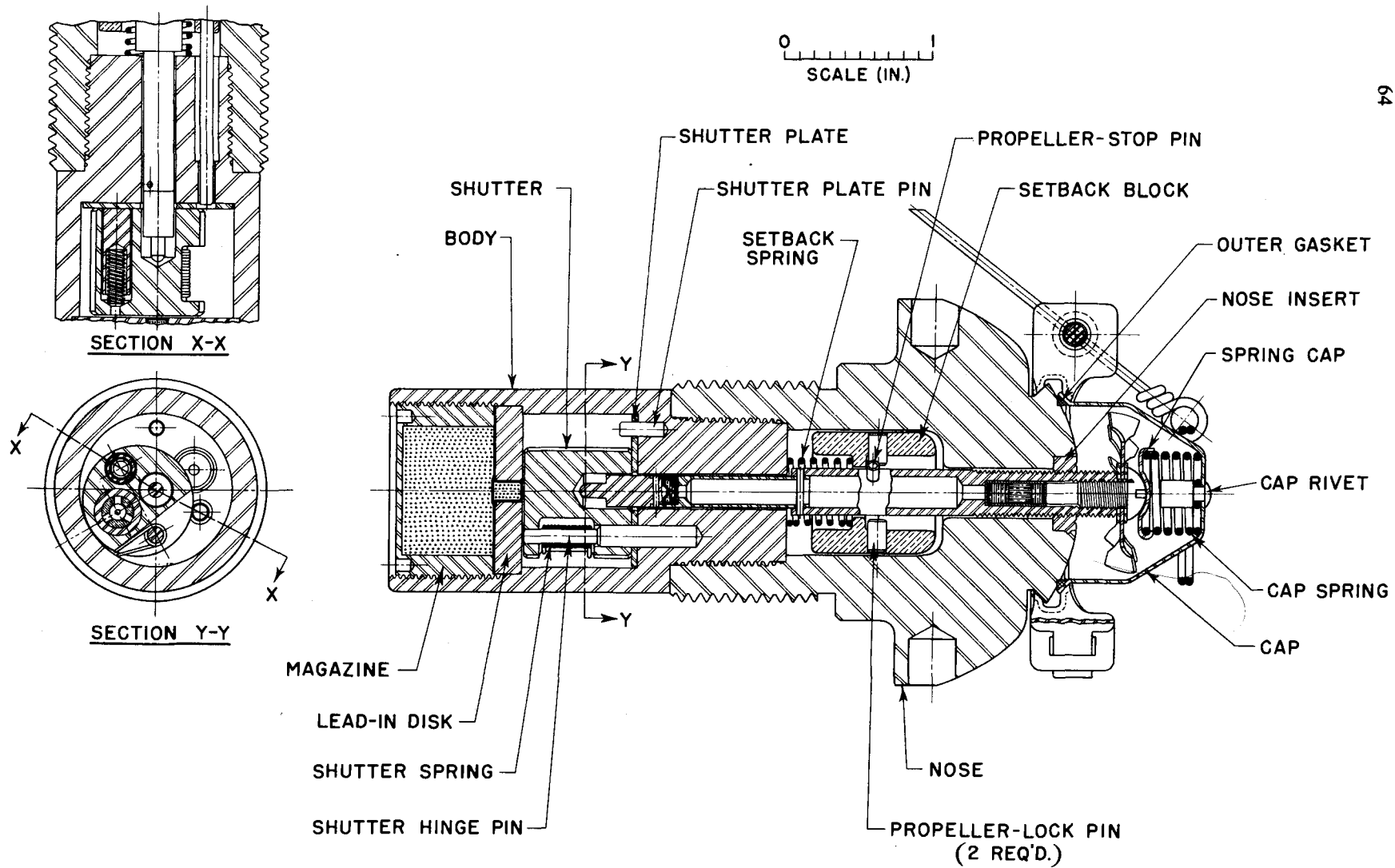


FIG. 31. AIR-9 Mod 1 fuze, unarmed.

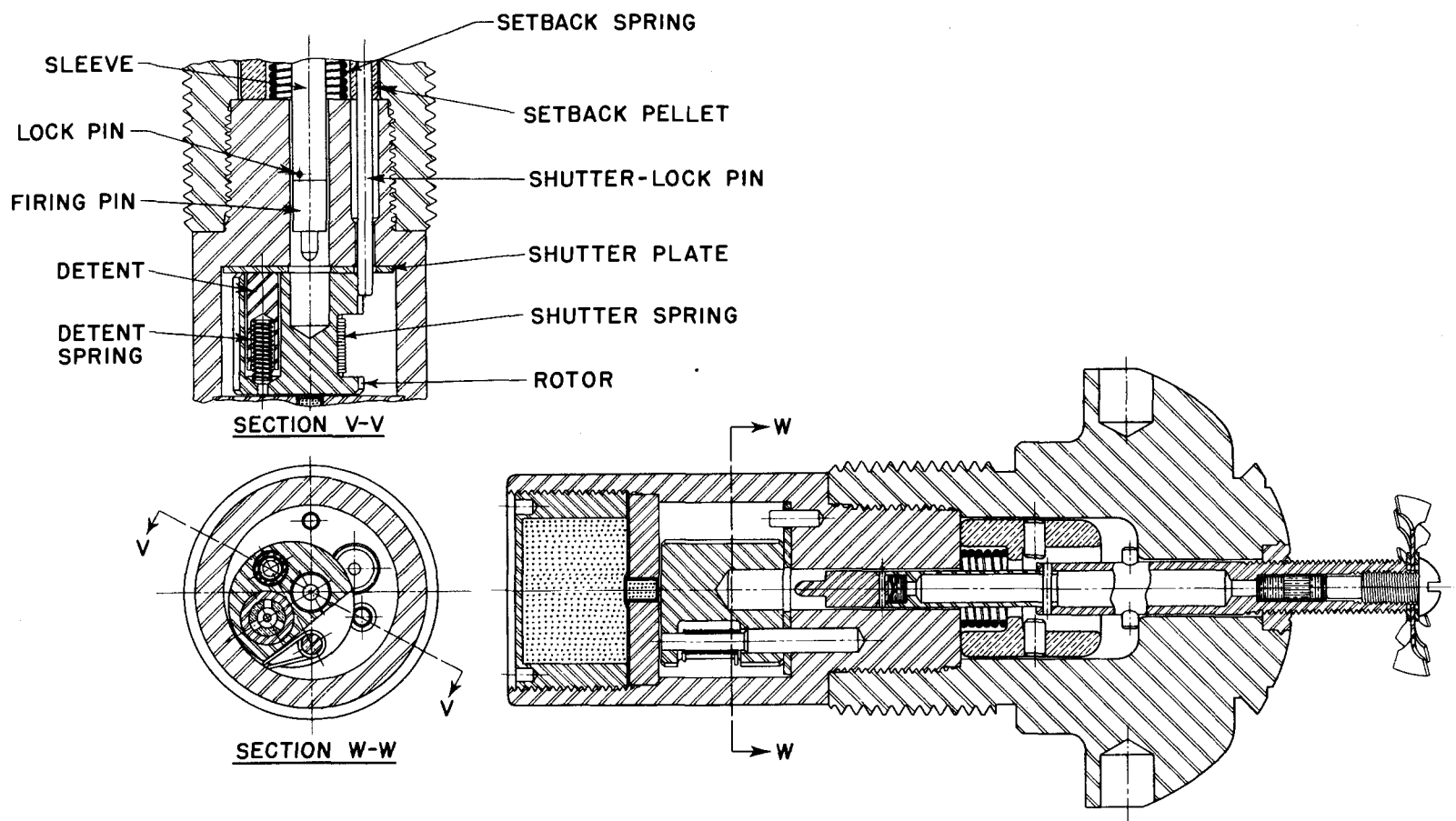


FIG. 32. AIR-9 Mod 1 fuze, showing position of parts during burning of rocket motor.

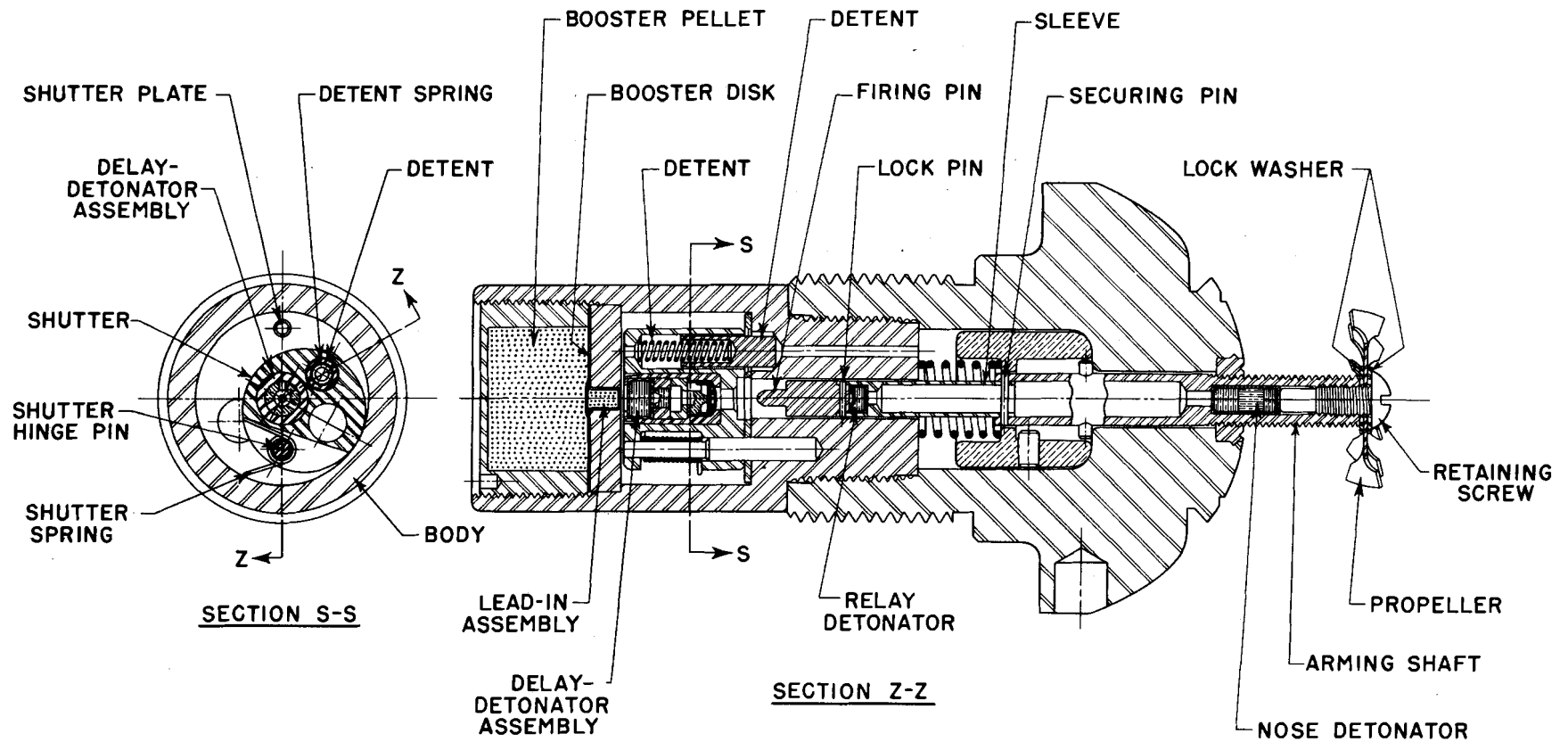


FIG. 33. AIR-9 Mod 1 fuze, armed.

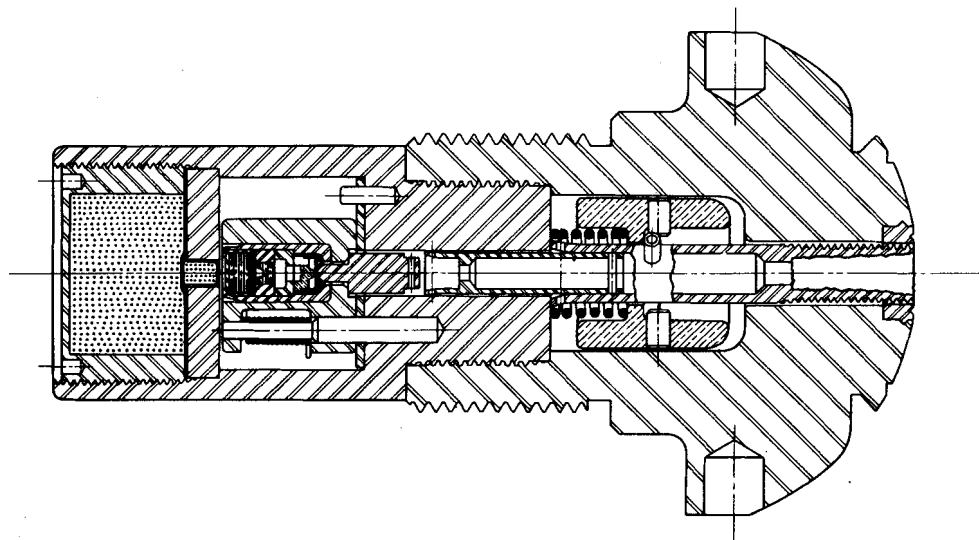


FIG. 34. AIR-9 Mod 1 fuze, fired.

However, any high-explosive contents must be detonated within the target to have the maximum effect; this fact determines the basic requirement for a satisfactory fuze—that it detonate the round within the target after a hit above water, or after a hit below water following widely varying distances of travel through the water. To this must be added the limitation that the shape of the rocket cannot be altered appreciably without affecting the underwater behavior. The general requirements for the fuze correspond to those for other aircraft rocket fuzes (AIR-8, for example), and will not be repeated here.

It is known that the initial deceleration of the rocket on water impact is comparable to the deceleration on light plate. For example, those PIR type fuzes that will not function consistently on $\frac{3}{8}$ -in. mild steel plate, will function, at various entry angles and comparatively low velocity (700 ft/sec) on water, provided only that the round has some stability under water. Therefore, a simple inertia-firing fuze could not be used. However, it seems quite certain that there would be a great difference in the deformation of the nose of the projectile occurring on water impact and that occurring on plate impact. It was decided to try to use a point-detonating fuze, since it is fired by this deformation. It was realized at the time that the inclusion of the required pyrotechnic delay in a nose fuze would limit the thickness of plate that could be penetrated satisfactorily. Because it was anticipated that the rounds would be used principally against merchant shipping, unarmored warships, and submarines, it was specified that the fuze function satisfactorily on plate up to 1 in. STS. It seemed that it would be possible to attain this.

2.092. OPERATION.—Although many minor modifications of the AIR-9 fuze were made and tested, only the AIR-9 Mod 1, which represents the final form, will be described, various features of the other fuzes being mentioned in the discussion of the fuze development.

The fuze arms in the same manner as the AIR-8 (see 2.08) except that the setback-operated lock of the propeller-firing-pin assembly is entirely within the fuze body, operating through the interference of pins in the arming shaft (which corresponds to the firing pin in the AIR-8) and setback pellet.

On impact, the forward detonator in the arming shaft is initiated by shock and compression. This detonator flashes back through the arming shaft and initiates the second (smaller) detonator. This second detonator shears a lock wire and forces the firing pin against the percussion primer of the delay-detonator assembly, which, after the required delay, detonates the explosive train of the fuze and thus the main filler of the head.

2.093. PERFORMANCE.—The AIR-9 Mod 1 fuze was never standardized or produced in quantity. However, a considerable number were made and tested, and interesting and possibly valuable information was obtained. The anticipated performance of the fuze, as indicated by tests, is summarized below.

1. PERFORMANCE ON WATER.—Numerous tests of the water discrimination of earlier modifications of this fuze have been made. In these earlier modifications the force of impact was communicated to the primer of the delay-detonator assembly by direct mechanical means, there being no auxiliary detonator in the arming

shaft. A telescoping firing pin of the same type as in the PIR-2 or the Mk 145 fuze was used. A fairly accurate picture of this firing pin may be obtained by neglecting the arming shaft detonators of the AIR-9 Mod 1 fuze. Water discrimination was then obtained by adjusting the strength of the thread in the fuze body that engaged the firing pin and prevented its moving back on impact. The hub placed behind the propeller on other AIR fuzes to assist in firing them on light or "soft" impacts is omitted in the AIR-9.

Ground-fired tests showed that the minimum strength of this shear thread in the fuze body necessary to make the fuze water-discriminating at the velocities obtainable with ground-fired rockets available at the time (approximate striking velocity of 1000 ft/sec at 6° incidence) was one-twelfth that finally specified for the fuze.

Aircraft-fired tests showed that with half the shear strength finally specified, the fuze was water-discriminating at a striking velocity of 1400 ft/sec and an incidence angle of approximately 45°. This was not determined to be a minimum value of the shear strength, but only an effective value.

The AIR-9 Mod 1 has been determined to be water-discriminating only at striking velocities of about 1000 ft/sec. However, fulminate of mercury-filled nose detonators, which contain some fulminate primary mixture and are appreciably more sensitive than the straight lead azide detonator that would normally be specified, were used, and therefore it does not seem likely that any difficulty would be encountered at higher striking velocities (up to 1800 or 1900 ft/sec at least). If it should be found that the fuze will fire on water impact at higher velocities, it would seem that such simple expedients as increasing the mass of the retaining screw or providing a lead or cork cushion for the forward detonator should correct this.

2. ARMING DISTANCE.—The setback arming delay makes the arming distance of the fuze slightly greater than the burning distance of any rocket in which it is used. The partial arming distance (distance from the launcher at which the firing pin is completely screwed out and the shutter is held in the *safe* position only by the setback lock) has not been determined. However, the material and blade angle of the propeller (0.024-in. steel and 45° respectively) and the distance of the propeller from the nose of the fuze were determined so that the fuze would just arm when used in ground-fired 11.75-in. AR at high propellant temperatures.¹ It is known that the AIR-8 will arm consistently in ground-fired 5.0-in. AR at a propellant temperature maximum of about 100°F. Under these conditions the two rockets have the same burning time, and burnt velocities of 810 and 720 ft/sec, respectively. It may therefore be said that the AIR-9, launched under the same conditions in the same rocket, will have a partial arming distance equal to, or slightly greater than, that of the AIR-8.

3. PERFORMANCE ON PLATE.—The Air-9 Mod 1 fuze will function consistently on ¼-in. mild steel plate at striking velocities greater than about 500 ft/sec and at

¹ Since only a few rounds were tested, the values were only approximate.

obliquities up to about 60°. It will probably function on plate as thin as $\frac{1}{8}$ in., on concrete, or on earth containing small stones larger than about one inch in diameter, and may function on sand or earth at higher striking velocities.

The fuze will function properly on at least 1-in. mild steel plate at obliquities up to 50° to 60°. However, whether or not the head will be detonated on the heavier impacts at higher velocities depends on whether the fuze and head become separated within the delay time of the fuze. The possibility of separation of the fuze and head is discussed below.

The earlier modifications of the fuze would seldom fire properly on any plate impacts at all, because of certain characteristics of the pyrotechnic delay included in the fuze. As was mentioned in the Introduction (1.04), a short fixed time delay is commonly obtained by placing a highly compressed pellet of black powder in the explosive train of a fuze. Black powder is used for short delays because it is presumably the only mixture which, on burning through, gives a flame of the proper sort to initiate a detonator and is at the same time suitable in other respects. It must be highly compressed, since it must be exposed to the primer flash on one face, and to the relay detonator on the other, and therefore must be strong mechanically to support itself on heavy impacts. The density of the pellet is so high that it will not burn uniformly under atmospheric pressure but requires a small closed chamber to hold a higher pressure over it. The cap of the percussion type primer forms one wall of this chamber and is necessarily not very strong mechanically. If pinched very hard between the firing pin and the anvil, it will be quickly punctured, hence the firing pin must not be allowed to come too close to the anvil. On the other hand, the layer of primer mix, which must be pressed between the anvil and the firing pin with the primer cap interposed, is quite thin. As a result, the total variation in the penetration of the firing pin into the primer must be controlled to within a few thousandths of an inch.

On being fired against plate, the protruding arming shaft of the AIR-9 fuze strikes before the rest of the fuze. It may perforate light plate, as has been observed for $\frac{1}{8}$ -in. plate at a low striking velocity of 500 ft/sec; it certainly will not perforate heavier plate. In either case, it will acquire a high velocity with respect to the fuze equal to a substantial fraction of the velocity of the rocket. It is precisely this velocity difference between the protruding parts of the firing pin and the fuze proper that is used in point-detonating fuzes to initiate the primer; in the early modifications of the AIR-9 fuze, it initiated the primer of the delay detonator assembly directly, a telescoping joint being used in the firing-pin assembly to reduce the force on the primer. However, it was soon discovered that the strength of this telescoping joint, that is, the amount of mechanical coupling between the arming shaft and the firing pin, was very critical. If the coupling was weak, then the velocity imparted to the firing pin proper was small, and sufficient deformation of other fuze parts to prevent further motion of the firing pin would occur before the firing pin struck the primer. If the coupling was stronger, the velocity imparted to the firing pin was so great that the penetration of the firing pin could not be controlled, and the primer cap would be punctured. Alloy steels with yield points over 200,000 lb/in.² were used in the parts concerned with controlling this penetration, but without success. Although it probably can be solved, the problem of

obtaining the proper strength of the mechanical coupling in this case is obviously difficult,¹ and the "pyrotechnic coupling" used in the AIR-9 Mod 1 was tried as a substitute.

The advantages of this pyrotechnic coupling are apparent. The nose detonator is initiated at the very beginning of impact, and the shock wave, traveling through the hollow arming shaft at a velocity several times the rocket velocity, initiates the second detonator² well before any appreciable distortion of the fuze can occur. This detonator imparts essentially the same energy to the percussion firing pin regardless of the magnitude of the impact, provided the impact is enough to fire the forward detonator. It was found that this method of firing the percussion primer was quite satisfactory for plate up to 1 in. thick, at striking velocities up to 1500 ft/sec, with no indication that this was an upper limit.

Throughout a good part of the development of this fuze it was unfortunately true that the proper heads for use with the 5.0-in. motor—the sphere-ogive or "underwater" head (CIT 5.0-in. Head Model 31, BuOrd Type Ex-1)—were not available, although the necessary information regarding the external shape of the head had already been determined when development of the fuze was first started. Although this had the advantage that the head and fuze could be redesigned as seemed desirable to give optimum plate characteristics, testing had to be done with other heads and adapters of various sorts, all of which broke up on plate of the thickness usually used. The fuzes, always fired partially loaded in these tests, were separated from the head or head fragments when recovered. It was not until 5.0-in. underwater heads in small quantity were finally procured that one of the fundamental objections to a delay nose fuze was discovered, namely, that on plate appreciably below the ultimate limit for the head and fuze and at fairly high striking velocities, the fuzes separated from the heads through failure of the connecting thread. The diameter of this thread for the AIR-9 was made as small and the shoulder as wide as possible, to give maximum strength on impact. It was found that over a certain fairly wide range of plate thickness (which varies with the striking velocity) this shoulder would deform just enough to allow the thread to be stripped. On heavier impacts the head itself is deformed enough to hold the fuze in place, and on lighter impacts the thread is not stripped. How long after single-plate impacts the fuze stays in the head has not been determined, since the fuzes were generally fired only partially loaded. It is possible that it stay in longer than the delay time of the fuze, in which case the head will be detonated; however, this does not seem likely, and the fuze will certainly not remain in the head for the full delay time on multiple impacts. Any appreciable strengthening of the shoulder or thread is not possible. The methods of overcoming this difficulty suggested in the design of the AIR-10 and AIR-11, however, may be successful.

2.094. REMARKS.—When the development of this fuze was begun, it was antici-

¹ This suggests the possibility of developing a nose fuze that will fire on "soft" impacts such as water or earth, but will not fire on plate at all, or only on plate heavy enough to break up the rocket head.

² The fuze as tested used the sensitive primer from the Fuzes Mk 19, 20, etc. for the second detonator, since these were available. Straight lead azide-filled detonators of about the same dimensions as those shown on the drawings should really be used for both these detonators.

pated that heavier impacts might displace the shutter during the delay time, so that when the relay detonator fired it would not be in line with the lead-in. However, it was decided to attempt to use a shutter, rather than a rotor of some type, because of its greater simplicity. The hinge pin and detent were made as strong as possible, and the firing pin was so designed that it served as a detent under certain conditions. On the basis of fairly extensive tests it appears that this shutter would be satisfactory up to the limiting plate for the 5.0-in. underwater head.

It was also known that the performance of the delay-detonator assembly from the Nose Fuze Mk 145 was not entirely satisfactory. This delay assembly was designed to fit a limited space in the Mk 145. As a result (1) the pressure chamber over the delay pellet is too small, so that the pellet burns at too high a pressure, (2) the delay pellet is not adequately protected from the shock wave of the primer by baffles, and (3) the method of securing the assembly by crimping the outer case (required by the space limitations) makes adequate obturation or sealing of the pressure chamber difficult. In addition, the relay detonator is too small, so that small malalignments of the detonator and lead-in may result in low-order functioning of the lead-in;¹ also, the whole assembly is not as strong mechanically as is desirable.

The AIR-9 Mod 1 will satisfy the requirements set up for a fuze for those aircraft rockets that have satisfactory underwater trajectories. However, it developed into a fuze more difficult to manufacture and load than was originally envisioned and is quite limited in its capabilities and possible uses. The DDR fuze (see Ch. 5), although about as difficult to manufacture and load, is more satisfactory in design, has a wide range of possible applications, and has considerably fewer limitations. For these reasons the DDR has been preferred over the AIR-9 and has been adopted by the Navy.

¹ Note that a larger relay detonator, which appears to be satisfactory, may be used as in the PIR-19 fuze (see 3.15).

2.10. AIR-10 FUZE

Rockets in which used

Same as AIR-9 Mod 1 (see p. 62)

Dimensions and weight

Approximately the same as the AIR-9 Mod 1

Material

Same as AIR-9 Mod 1

Explosive components

Nose detonator: same as AIR-9 Mod 1

Relay detonator: same as AIR-9 Mod 1

Delay assembly: from Projectile Fuze Mk 20 (except smaller relay detonator)

Detonator: from Nose Fuze Mk 137

Lead-in: from Nose Fuze Mk 137

Booster: same as AIR-9 Mod 1

General arrangement drawing

CIT Drawing No. C10-01

2.101. GENERAL.—The AIR-10 is a water-discriminating nose fuze intended to meet the same requirements as the AIR-9 and AIR-11. It never progressed beyond the stage of assembly drawings, including the establishment of certain critical dimensions to insure that the design was mechanically practicable, because, at first, the time available was used for work on the AIR-9 and AIR-11, and later, because development of the nose fuzes was discontinued in favor of the water-discriminating base fuze DDR (see Ch. 5).

In designing the AIR-10 fuze it was desired to overcome insofar as possible the known weaknesses of the AIR-9 Mod 1 fuze, principally (1) the separation of fuze and head on intermediate impacts, (2) the possibility of the detonator shutter being forced out of position on heavy oblique impacts, and (3) the not entirely satisfactory performance of the delay detonator assembly from the Nose Fuze Mk 145.

2.102. DESCRIPTION.—In the *safe* condition the arming shaft is prevented from turning by the cap and by interference between the propeller-lock pin (attached to the arming shaft) and the propeller-stop pins (attached to the setback block), and the detonator rotor is prevented from turning by the rotor-stop pin (also attached to the setback block). When the round is launched the setback block moves back, freeing the arming shaft. Removal of the arming wire allows the cap and clamp to fly off (as in the AIR-8), and the propeller starts to turn. After about 11 turns the propeller-lock pin reaches the forward end of the nose cavity, and the arming shaft is stopped. At the end of burning of the rocket motor the setback block moves forward until it is stopped by the forward end of the cavity, carrying the rotor-lock pin forward far enough to free the detonator rotor. The rotor pin, under the influence of the rotor spring, turns the rotor 90°, lining the detonator up with the relay detonator of the delay assembly and with the lead-in. The rotor is locked in this position by the two detents engaging in two holes in the rotor.¹

¹ The delay assembly is rigidly held in the fuze body, and is not moved in the arming process.

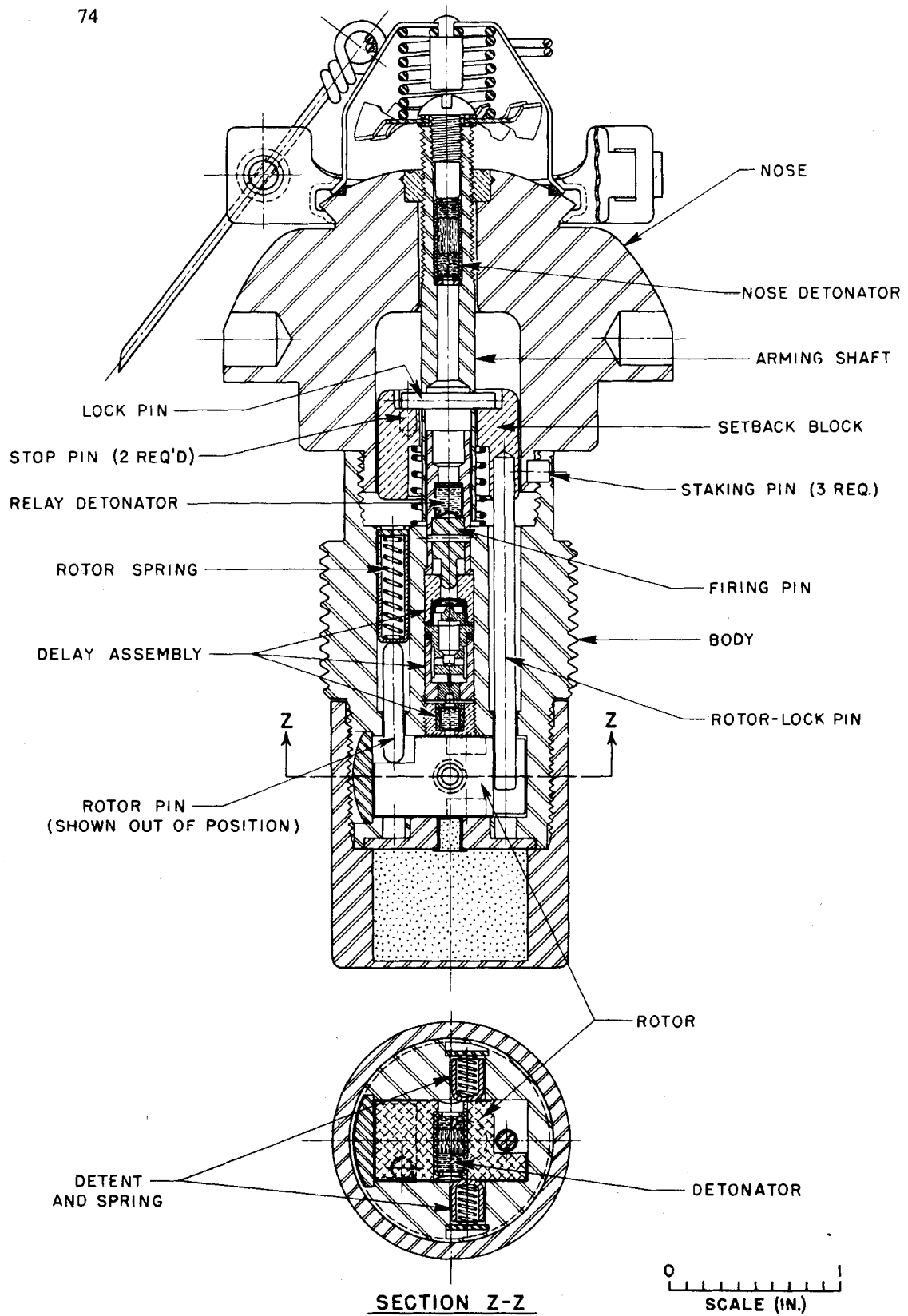


FIG. 35. AIR-10 fuze, unarmed.

On striking steel plate or other "hard" target, the nose detonator is initiated by shock and compression, flashes back through the hollow arming shaft, and initiates the second detonator, which forces the firing pin against the percussion primer, thus initiating the explosive train of the fuze.

2.103. DISCUSSION.—No AIR-10 fuzes have been made or tested, except that two were subjected to a 50-ft nose drop (see 1.08), to test one obviously questionable feature of the design, namely, that safety on a nose drop depends primarily on the strength of the stop-pin in the arming shaft; this pin prevents the setback block from moving forward and allowing the fuze to arm. The pin was found to be strong enough, and it was noted that although the nose detonators were badly crushed, they were not fired, because of the low impact velocity.

It is anticipated that this fuze would be more satisfactory than the AIR-9, especially on heavier impacts, because of the sturdier and more reliable delay element and because the rotor cannot be easily displaced.¹ In addition, the weakened section between the fuze nose and the fuze body should insure that on those impacts where the nose is only slightly deformed, the external fuze thread will not be stripped (as it would be in the AIR-9—see 2.09 and 2.11), so that the parts of the fuze containing the explosive train should remain in the head over the entire range of plate impacts that the head will withstand.

Should any further requirement for a water-discriminating nose fuze exist, it is believed that development should proceed along the lines indicated by the AIR-10.

¹ Other methods of moving the detonator into line that are as satisfactory in this respect are possible, and may be preferable for other reasons.

2.11. AIR-11 FUZE

Rockets in which used

Same as for AIR-9 (see p. 62)

Explosive components

Sensitive primer: from Mk 19 fuze

Delay-detonator assembly: from Mk 145 fuze

Lead-in: from AIR-9 fuze

Booster: from AIR-9 fuze

General arrangement drawing

CIT Drawing No. C11-01

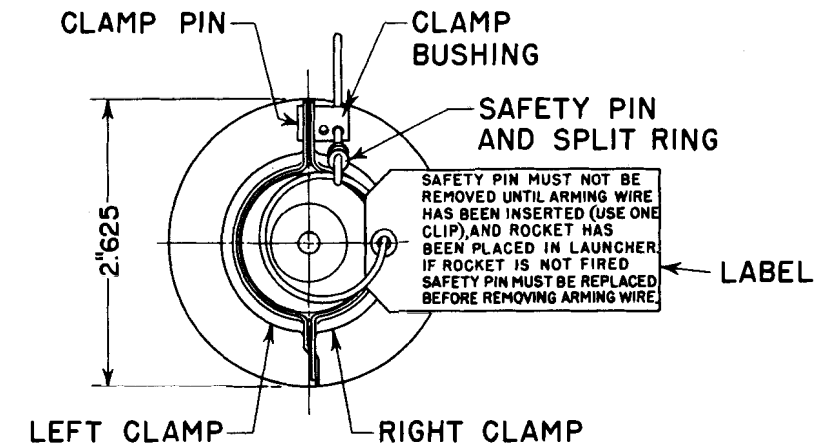
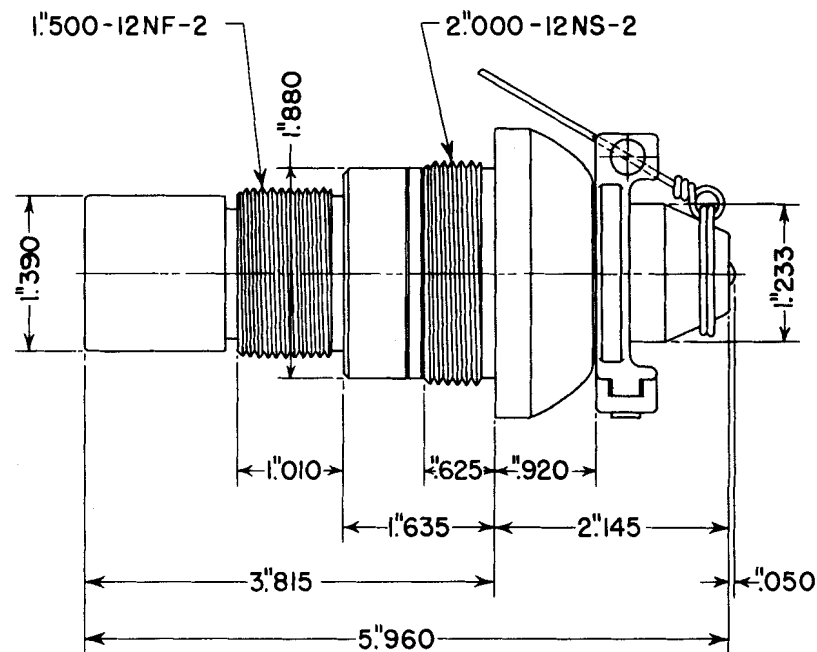
2.111. GENERAL.—The AIR-11 fuze is a water-discriminating nose fuze whose development was begun as an alternative to the AIR-9 and AIR-9 Mod 1. The requirements were the same as for the AIR-9, and in the AIR-11 an attempt to meet them was made by utilizing a stab-type firing pin and sensitive primer to initiate a delay detonator, and substituting a detonator rotor for the hinged shutter. With the exception of these two features the design and operation of the AIR-11 fuze are essentially the same as for the AIR-9.

The detonator assembly consists of a sensitive primer, delay-element firing pin, and delay-detonator assembly, so that it is similar in general to that used in projectile base fuzes (Mk 20, etc.). The stab-type firing pin, after initiating the sensitive primer, shoulders against the rotor and telescopes, as in the Mk 145 fuze. The objective here was to initiate the percussion primer by means of the delay-element firing pin, the impact of which on the primer would be controlled by the sensitive primer and not by the impact of the projectile.

The detonator rotor is similar to that used in the PIR-9 fuze (see 3.10) with the addition of a spring-loaded detent in the hole occupied by the firing pin. A rotor-locking pin attached to the setback block was provided to lock the rotor in the *unarmed* position during acceleration of the rocket.

Only preliminary tests of the performance of the AIR-11 fuze against various thicknesses of steel plate were conducted.¹ These gave encouraging results, although early models of the fuze, in external shape and general details of construction of the fuze body and nose, were identical with the AIR-9, having only a single external thread, and, like the AIR-9, tended to be torn out of the head over a certain range of impacts. The particular arrangement of the external threads shown in Fig. 36 may solve this problem. Both the 1.50-12 thread and the 2.00-12 thread engage in the rocket head, the 1.50-12 thread being on a separate retaining sleeve that can move longitudinally with respect to the rest of the fuze. A comparatively soft Dural washer is used to separate the sleeve and the fuze nose, so that the fuze nose can be deformed and moved back appreciably without affecting the sleeve. The fuze body, which contains all the explosive components, is retained in the head by the sleeve, even though the fuze nose may be separated from the head. On heavier impacts, when the threads on the sleeve may be stripped, the over-all deformation of the nose of the head and of the fuze should be sufficient to hold the fuze body in

¹ CIT/PMC 2.58, 12 November 1944, Part 2, p. 4.



DIMENSIONS SHOWN ARE MAXIMUM

FIG. 36. Outline view of AIR-11 fuze.

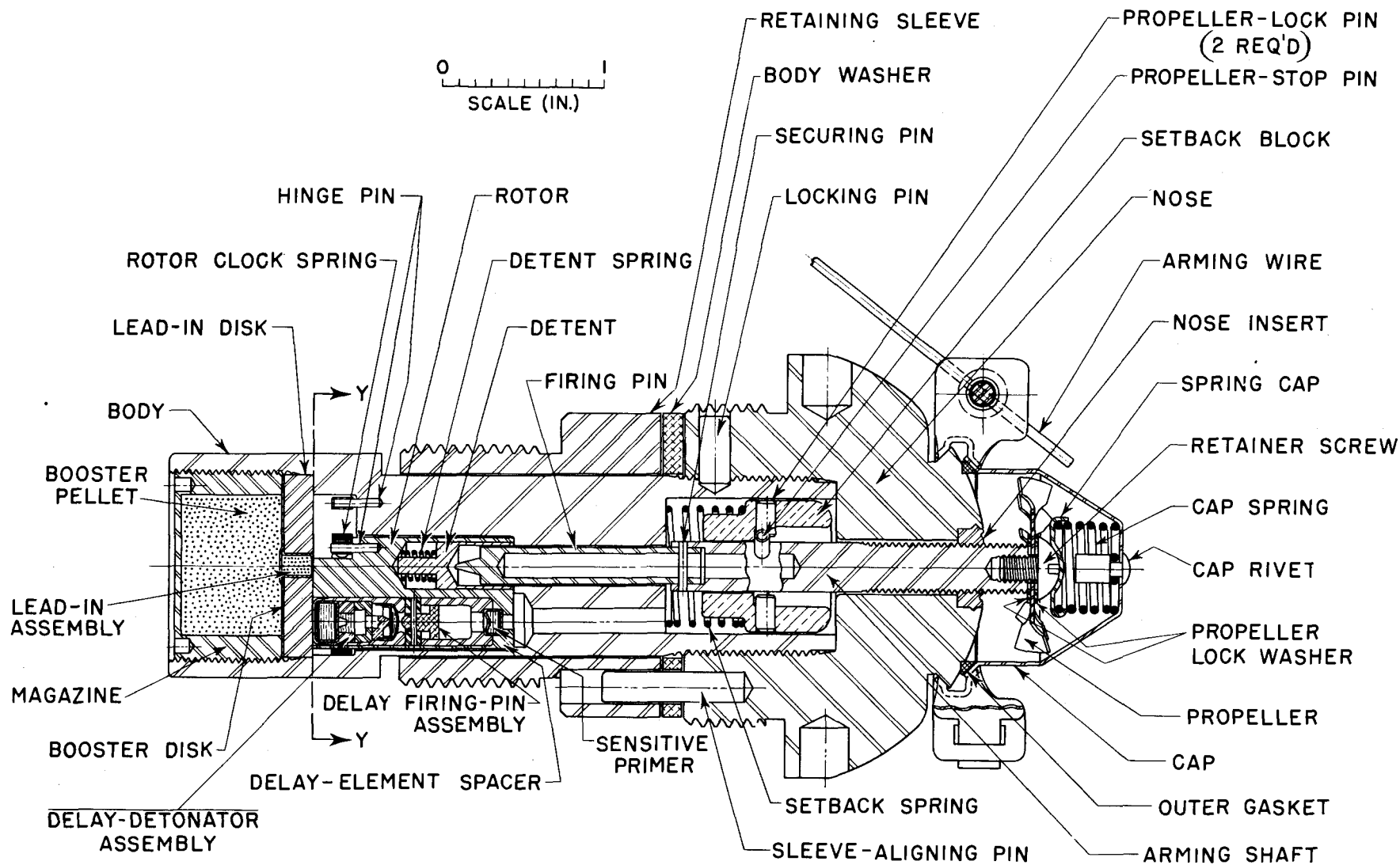


FIG. 37. AIR-11 fuze, unarmed.

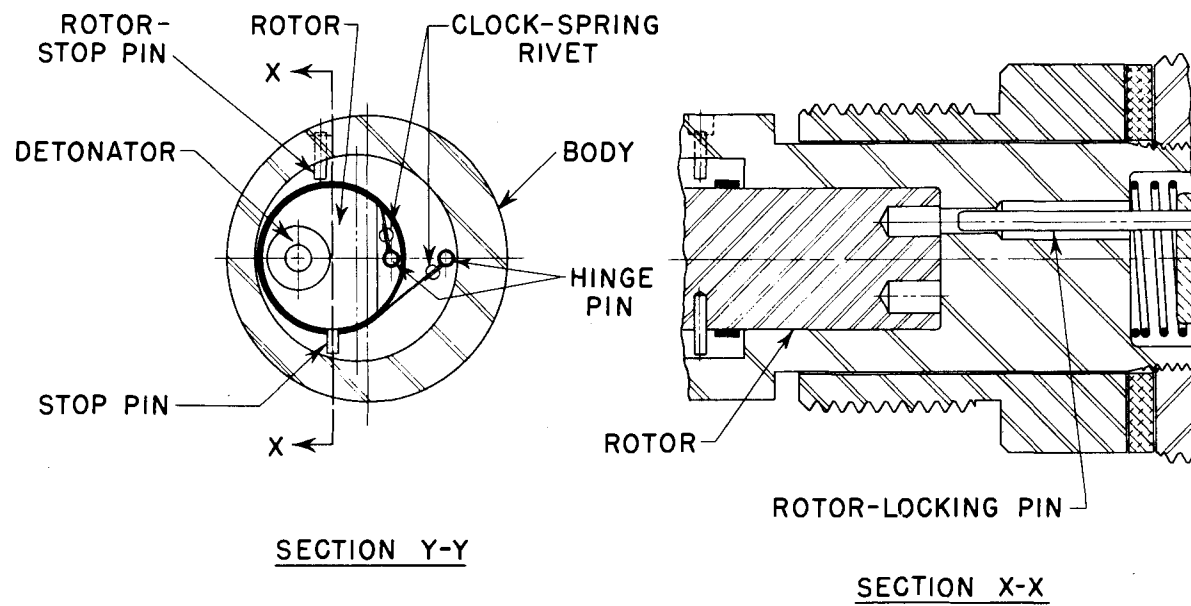


FIG. 38. Sections of unarmed AIR-11 fuze shown in Fig. 37.

the head. One test, fired against 1.0-in. mild steel plate at a striking velocity of 1200 ft/sec, indicated that this supposition is correct, but tests over the full range of impacts possible are obviously required. The changes required in the 5.0-in. head before it will accept this fuze weaken the head itself slightly, of course, whereas they should not weaken the 11.75-in. head appreciably.

The development of the AIR-11 fuze was discontinued in favor of the water-discriminating base fuze, the DDR (Ch. 5).

2.12. AIR-12 FUZE

Rockets in which used

5.0-in. High-Velocity Aircraft Rocket, with 5.0-in. Motor Mk 1 and 5.0-in. Head Type Ex-1 (sphere-ogive)
11.75-in. Aircraft Rocket

Dimensions and weight

Over-all length: 4.45 in.
Thread: 1.5"-12NF-2
Weight: 2.25 lb

Explosive components

Same as Mk 137 (AIR-2) fuze

General arrangement drawing

CIT Drawing No. C12a-01

2.121. GENERAL.—The development of the AIR-12 was undertaken to provide a selective-arming¹ instantaneous nose fuze for the 5.0-in. HVAR with the special underwater sphere-ogive 5.0-in. Head Type Ex-1.

The 5.0-in. CIT Model 31 Head (BuOrd design Type Ex-1) was developed to give the 5.0-in. HVAR a stable underwater trajectory. The design for the outside shape of this head was based on the fundamental work on underwater trajectories of 5.0-in. Aircraft Rockets performed by CIT.² The 5.0-in. Head Model 31 has a hemispherical nose 2.75 in. in diameter followed by a 20-caliber (100-in. radius) ogive. This shape gives the 5.0-in. HVAR an underwater trajectory having minimum drag and continuing approximately in the line of the air trajectory. It thus prevents the breakup or ricocheting of the round on water impact which occurs with the 5.0-in. Mk 6 head unless a flat nose plug, in place of the normal conical nose plug or Nose Fuze Mk 149, is used. The 5.0-in. Ex-1 head shape has also been shown to give this rocket a stable underground trajectory. As a consequence of these characteristics the 5.0-in. Model 31 head with the DDR (Mk 166) base fuze makes effective attacks on shipping and shore installations possible where penetration of a target after relatively long travel through water or earth is required (for example, in hits short of a ship which will strike the hull below the water line).

It was desired to make the 5.0-in. Model 31 head a general-purpose head useful in strafing attacks as well as against targets where penetration is required. This called for an instantaneous nose fuze, similar to the Mk 149 (AIR-8) fuze, to be launched either *safe* or *armed* at the discretion of the pilot. However, to conform to the contour of the nose of the head required to give a stable underwater or underground trajectory, the nose of the fuze body must be hemispherical in shape. The fuze body must also be tough to assist in preventing breakup of the nose of the head on heavy impacts (for which the nose fuze is launched *safe*, to obtain the delayed action of the base fuze).

¹ Capable of being launched either *safe* or *armed*.

² *Further Investigations of the Underwater Behavior of Aircraft Rockets*, CIT/JBC 27 (OSRD Report Number 2152), I. S. Bowen, 26 June 1944.

The first design of the AIR-12 tested¹ was essentially a Mk 149 (AIR-8) fuze with a hemispherical nose body adapted to the 5.0-in. Model 31 head. The only parts in this fuze that were not standard Mk 149 parts were the body and the clamp. Preliminary tests² of this design suggested that the openings in the nose of the fuze might be the cause of instantaneous low-order detonations obtained on water impact with the nose fuze launched *safe*. To avoid this possibility the fuze was redesigned and designated the AIR-12 Mod 1.

In the AIR-12 Mod 1 fuze the holes in the nose of the fuze body, with the exception of the threaded hole for the firing pin, were eliminated by incorporating the internal setback-operated firing-pin lock developed for the AIR-9 fuze. Aside from this feature the operation of the fuze was similar to that of the Mk 149. However, development of the AIR-12 Mod 1 fuze by CIT was terminated at the cessation of hostilities before any tests of it were performed.³

Other problems associated with firing a round with a nose fuze set *safe*, such as possible deflagration of the nose fuze explosive components and auxiliary boosters, also remain to be explored.

In addition to its use in the 5.0-in. HVAR, the AIR-12 Mod 1 fuze might be applicable to the 11.75-in. AR in the event a head with a nose fuze were developed for that rocket.

¹ CIT/CMC 2.85, 8 July 1945, Part 2, p. 1.

² CIT/PMC 2.89, 15 September 1945, Part 2, p. 5.

³ *Status of AIR-12 Nose Fuze for 5.0-in. Ex-1 Head*, CIT/OIC 12.1, R. E. Martin, 19 September 1945.

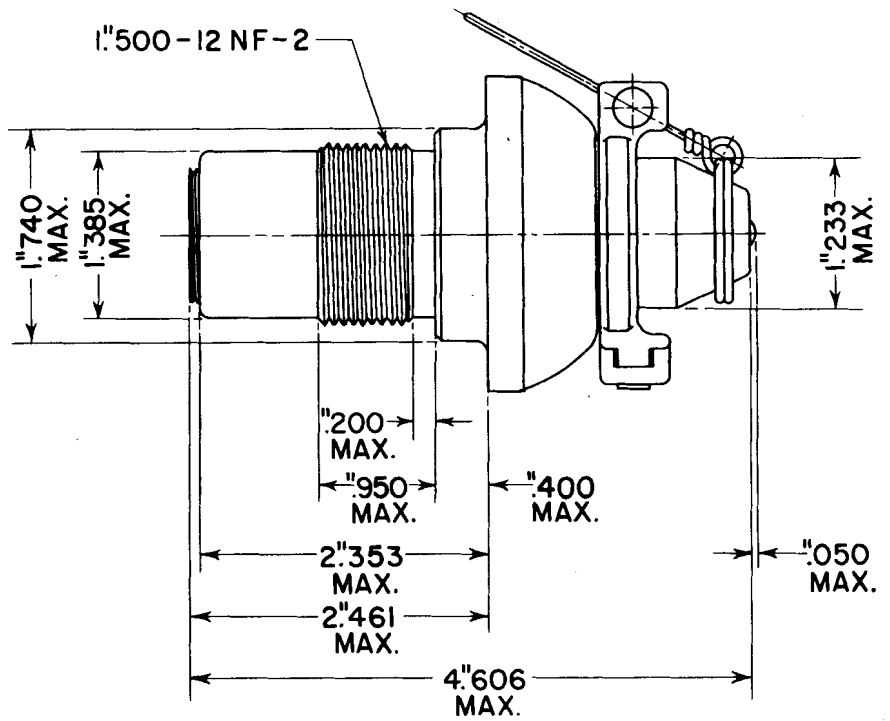
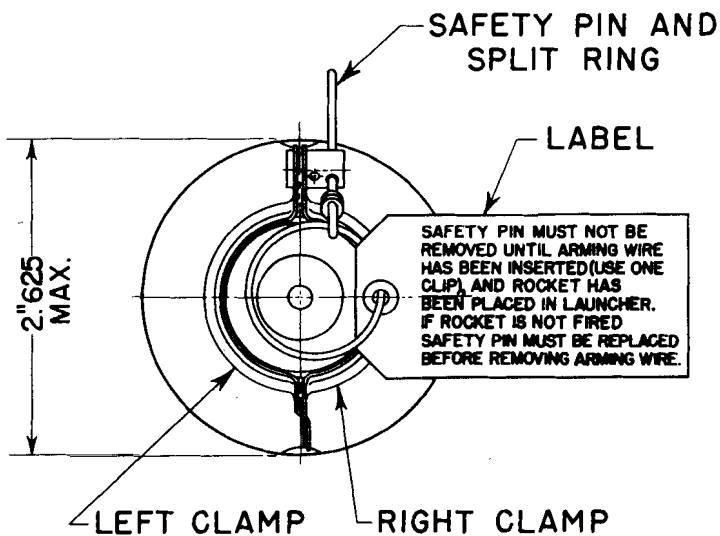


FIG. 39. Outline view of AIR-



WEIGHT - 2.75 LB

12 Mod 1 fuze.

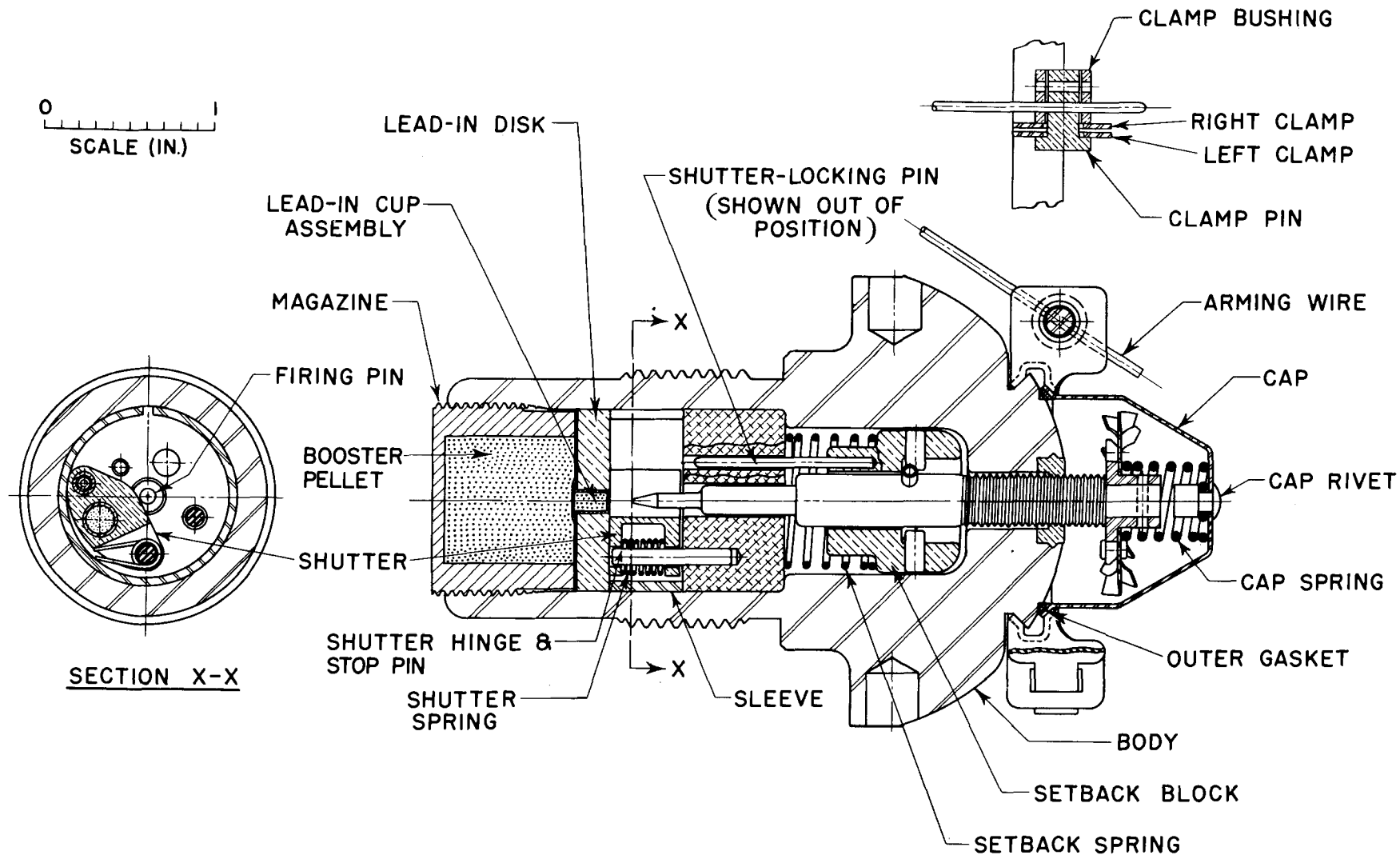


FIG. 40. AIR-12 Mod 1 fuze, unarmed.

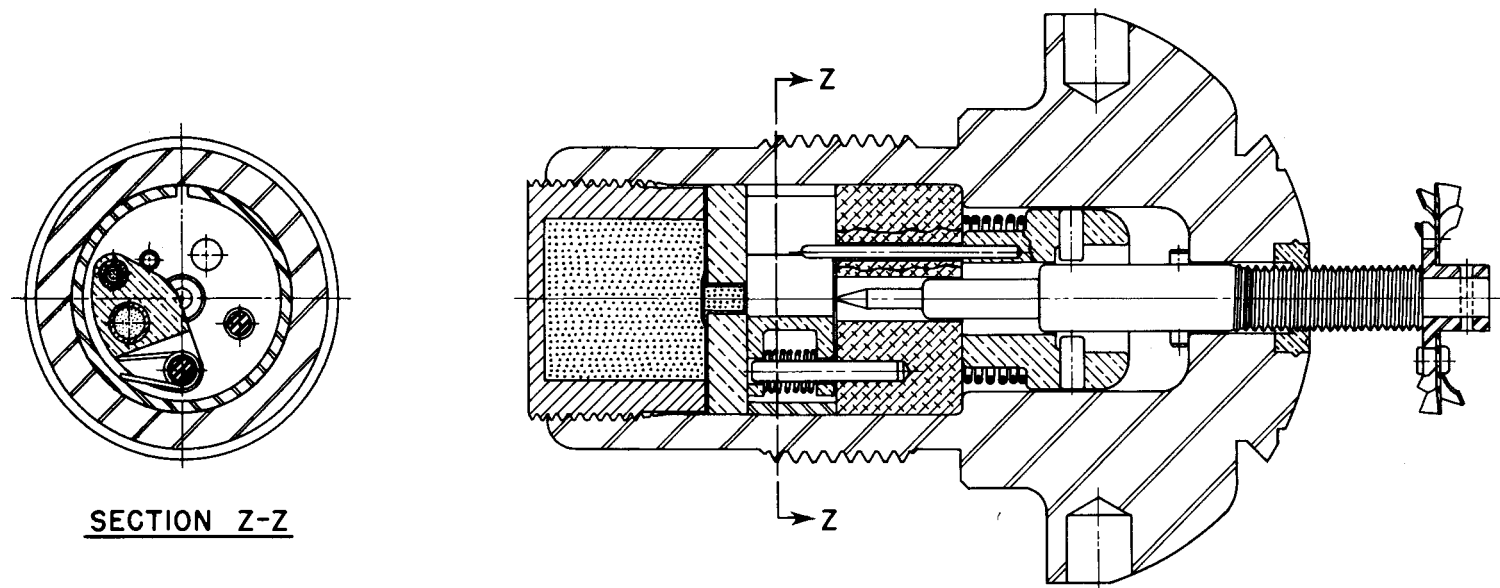


FIG. 41. AIR-12 Mod 1 fuze, showing position of parts during burning of rocket motor.

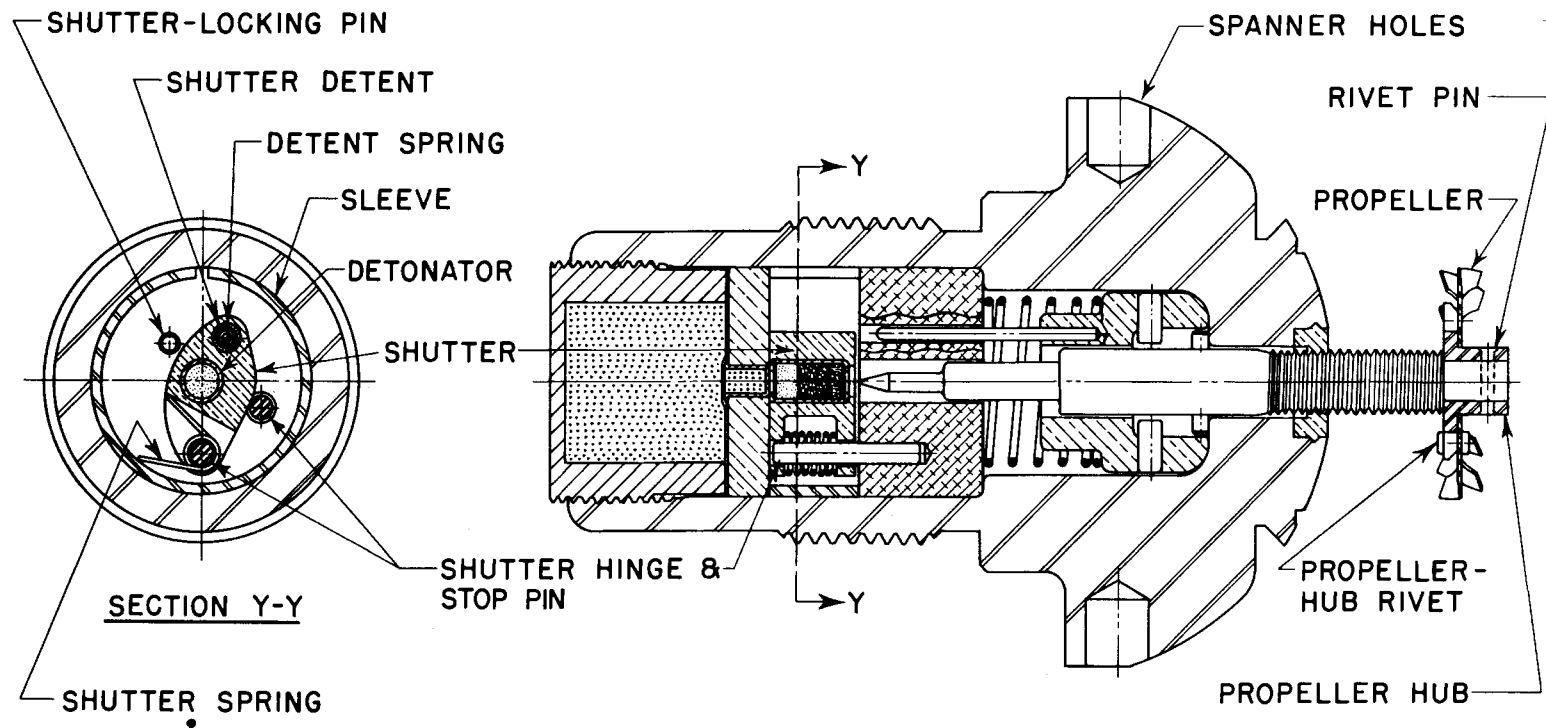


FIG. 42. AIR-12 Mod 1 fuze, armed.

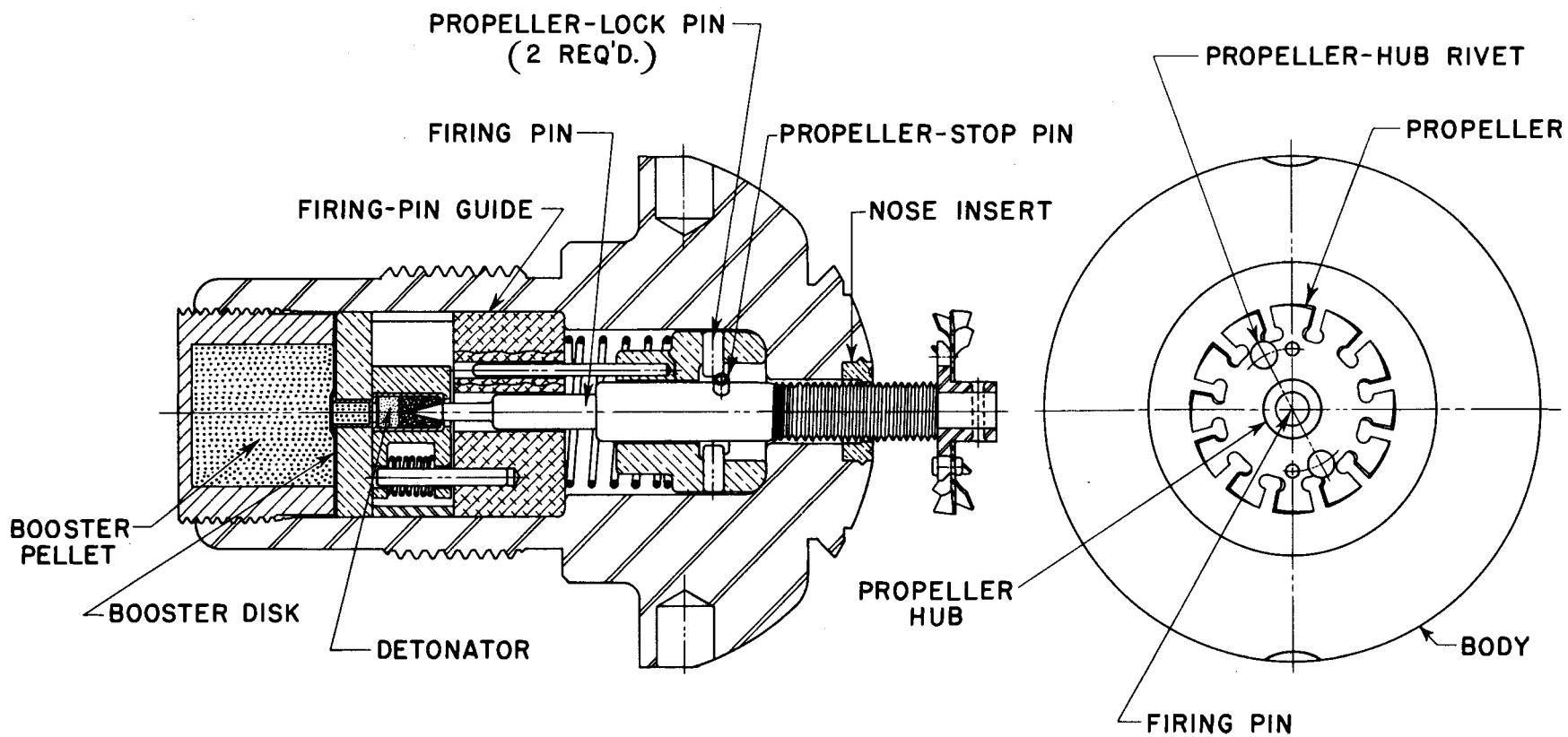


FIG. 43. AIR-12 Mod 1 fuze, fired.

Chapter 3

PIR BASE FUZES

3.00. INTRODUCTION.—The PIR series of base fuzes was developed for use in various fin-stabilized rockets. PIR signifies “pressure-arming, impact-firing, rocket” (fuze). The fuzes were developed for use in rocket heads where a short delay in firing after impact is desired, and are often used in conjunction with a selective-arming, point-detonating nose fuze. Since the principal use for the PIR fuzes has been in the aircraft rockets, the general requirements which influenced the fundamental design features arose from that fact. PIR fuzes developed for use in other rockets were modifications of the aircraft rocket fuzes.

3.001. PRINCIPLES OF OPERATION.—The general operating principles of all of the PIR fuzes except the PIR-22 are quite similar and are briefly discussed below.¹

1. ARMING.—The fuzes are armed by pressure from the gases in the rocket motor, which collapses a diaphragm in the fuze. The diaphragm moves an arming plunger locked by a shear wire and releases the firing pin; as in the AIR type of fuze, the firing pin holds a spring-loaded detonator shutter (or in some cases a rotor, to one side, so that in the *unarmed* position the detonator is out of line with the rest of the explosive train, and permits the firing pin to withdraw to the *armed* position. A delay in collapse of the diaphragm is obtained after ignition of the rocket motor, by admitting the gases into the fuze through a small orifice and thus causing the gas pressure to build up slowly over the diaphragm. A further delay in complete arming is obtained by utilizing acceleration forces to lock the detonator shutter in the *unarmed* position until burning of the rocket motor is completed.

2. FIRING.—The PIR fuzes are fired by impact when the inertia of the firing pin drives it forward into the primer of the detonator. In some fuzes (the PIR-1, for example) the detonator is instantaneous, and the delay in detonation of the head is due only to the motion of the firing pin before it stabs the primer of the detonator. In others, such as the PIR-2, a pyrotechnic delay element is used to obtain longer delays for greater penetration of the target before detonation.

3.002. GENERAL REQUIREMENTS.—The general functional and safety requirements for the PIR fuzes are essentially those described in the Introduction (Sections 1.05 and 1.06) for base fuzes used in aircraft rockets. In these requirements emphasis is placed on obtaining arming delays that will meet the safety specifications for rockets handled on aircraft carriers.

As in the case of practically all types of rocket fuzes, not all of the requirements that ultimately arose were clearly defined or understood at the beginning of the development of the PIR fuzes, but were recognized only as development, testing, and actual service use of the fuzes progressed. For example, the requirement that the operating parts should be strong enough to endure the heaviest impact which the rocket head could withstand appeared to be fulfilled in the 5.0-in. AR with

¹ A detailed description of the arming and firing operations may be found in Sections 3.023 and 3.024.

the 5.0-in. Mk 1 head by the Mk 146 (PIR-1) fuze. However, this fuze had an instantaneous detonator, and service tests showed that the delay action obtained in the motion of the firing pin on impact was insufficient for most tactical purposes. Because the Mk 146 had an instantaneous explosive train, the time available for the derangement or failure of parts due to the force of impact, before the explosive train detonated the head, was the extremely short time during which the firing pin moved forward to stab the primer of the detonator. In this time, which was less than 0.001 sec for heavy impacts, no appreciable distortion or derangement of parts due to inertia was possible. However, when a detonator containing a 0.02-sec delay element was introduced [PIR-2 (Mk 157) fuze] the time available for distortion of parts, between initial impact and detonation of the head, became significant, and the fuze design inadequate for the purpose. In an attempt to overcome this difficulty both minor changes and radical modification of the fundamental PIR design were tried. For thin-walled heads such as the 5.0-in. Mk 1, 5.0-in. Mk 6, and 11.75-in. Mk 2 head, the PIR-19 and PIR-12 types of fuze, which are relatively minor modifications of the PIR-2 design, appear to be adequate. For stronger heads of the common or SAP type such as the 5.0-in. Mk 2 head more radical design changes, as exemplified by the PIR-9 and PIR-22 fuzes, were definitely required. The specific shortcomings and limitations of the various PIR fuzes are discussed in the sections on the individual fuzes.

As a further example, the following safety requirement, not satisfied by the PIR type of fuze, arose long after these fuzes were standardized and in use in aircraft rockets: In aircraft rocket base fuzes arming must not take place except by a combination of pressure and setback forces acting simultaneously. This requirement arose from the fact that it became the practice to assemble rocket heads and motors and keep them in ready stowage aboard carriers pending their loading onto aircraft launchers. The assembled rounds were stowed in such a manner that should a fire ignite the rocket motors the rounds would not move appreciably. Under these circumstances it was highly desirable that the fuzes not be armed.

3.003. ARMING DELAY.—The problem of attaining a satisfactory arming delay, which would meet the requirements for safety against arming if motor failure should occur early in the burning time, determined many of the design features associated with arming the fuze. It was thought that among the forces available for arming a rocket base fuze the force due to pressure of gas from the rocket motor was the most readily utilized (see 1.023). In this case, to delay arming it would be necessary to retard the build-up of pressure in the fuze to the value required for arming until as late as practicable in the burning period of the rocket motor. The problems involved may be explained by discussing the function of individual parts concerned in the pressure phase of the arming process. The discussion following does not apply in detail to the PIR-22, whose arming features are identical with those of the DDR (Mk 166) fuze, or to the PIR-9 fuze.

1. DIAPHRAGM.—The diaphragm has two functions, (1) to seal the fuze body cavity from the motor gases, and (2), under pressure of the gases in the pressure chamber over the diaphragm, to collapse in such a way as to operate the arming plunger and sever the shear wire. The diaphragm adopted for use in the majority of the PIR fuzes (0.020 in. thick copper) was evolved from numerous earlier forms.

The factors that determined the characteristics (shape, diameter, thickness) of the diaphragm and thus in a large measure the size of the fuze head are listed below:¹

a. The diaphragm must be strong enough to force the arming plunger forward and shear the shear wire.

b. The diaphragm must be weak enough that the pressure necessary to collapse it alone is small in comparison with that required to operate the arming plunger (see Item 3 below).

c. It must provide an effective gas seal against high pressure in the pressure chamber.

2. **ARMING PLUNGER.**—The arming plunger, held by the shear wire, retains the locking ball which holds the firing pin in the *safe* position. The principal requirement is that it be extremely light so that inertial force from dropping or from vibration does not shear the shear wire. At the same time the area of the head must be sufficient that the diaphragm, in pushing against it, is not punched through.

3. **SHEAR WIRE.**—The two functions of the shear wire are (a) to lock the parts in the *unarmed* position and (b) to be sheared and to release these parts only when the diaphragm, under pressure from the rocket motor, actuates the arming plunger. Thus the strength of the shear wire is determined by a compromise between safety and functioning, particularly in those fuzes used with rocket motors with low operating pressure. At minimum service temperatures the pressure available for arming in the majority of CIT rockets falls within the range 300 to 600 lb/in.² Thus for a motor such as the 3.25-in. Mk 7, the pressure of which at low temperature is little over 300 lb/in.², the fuze-arming pressure must be set at not more than about 290 lb/in.² This adjustment is made by selecting the proper shear wire. Actuation of the diaphragm requires about 75 lb/in.², the resistance of the shear wire accounting for the remainder of the arming pressure. In the PIR-1 design an arming pressure of about 290 lb/in.², obtained by use of a 0.057-in. diameter phosphor-bronze shear wire, is about the minimum that can be achieved with safety, since any weaker wire will be sheared by the inertia of the arming plunger in 40-ft drop tests. On the other hand, an arming pressure of about 350 to 400 lb/in.², obtained by use of a 0.064-in. diameter shear wire, is about the maximum that can be obtained without increasing the strength of the diaphragm.

The parts described above are concerned in determining the value of the pressure required to arm the fuze. Those below are primarily concerned with providing a delay in the build-up of pressure to the arming point after ignition of the rocket motor.

4. **PRESSURE CHAMBER.**—The pressure chamber formed by the plug and diaphragm provides an expansion chamber into which the gas from the motor enters through the inlet orifice. The volume of this chamber required to provide adequate delay in attaining the arming pressure is directly related to the diameter of the inlet orifice in the inlet screw. Thus, the volume is determined primarily on the basis of how small a hole it is practicable to drill in the inlet screw. The plug is

¹ These do not apply to the PIR-9 fuze, in which the arming plunger is attached directly to the diaphragm and no shear wire is used. The PIR-9 type of diaphragm may thus be much smaller in diameter and stiffer than that described here.

screwed down tightly against the flange of the diaphragm, and particular attention to the surfaces involved in sealing is necessary.

5. **INLET ORIFICE.**—The inlet orifice drilled in the inlet screw provides an opening between the pressure chamber and the interior of the rocket motor, the open end of which faces the plug. The inlet orifice must be of the proper size to provide the optimum delay in build-up of pressure in the pressure chamber. The factors which set the lower limit practicable in the orifice diameter are (a) the debris from the rocket motor which may clog the orifice, even though filtered, if it is too small, and (b) manufacturing considerations, such as drill size.

6. **INLET FILTER.**—The inlet filter under the head of the inlet screw serves to filter out debris from the burning of the propellant and other material in the rocket motor before the gas reaches the inlet orifice, and thus to prevent clogging of the orifice. A piece of brass window screen was used in most fuzes, but in some it was possible to obtain adequate filtering by means of radial grooves in a washer under the head of the inlet screw. These types were both replaced in later designs by a filter of compressed Inconel wire mesh which was found to give excellent results. The amount of filtering required was dependent on the characteristics of the rocket motor.

7. **INLET SHIELD.**—Rocket motors are closed at the front end by motor closure disks of various types and complexity, which are only lightly pressed in place in order to keep the motor, before assembly with the head, "nonpropulsive." When the motor is ignited the closure blows forward against the fuze. To prevent the motor closure from sealing off the inlet orifice, it was necessary to provide many types of fuze with an inlet shield to ward off and distort the closure disks and permit the motor gas to reach the orifice. In some motors a light "blowout disk" was set in the middle of the closure. When this was present the inlet shield was not usually necessary and it was replaced by a washer under the head of the inlet screw on top of the inlet filter.

8. **ARMING CONSTANTS.**—The parts described in the preceding sections are associated with the pressure phase of the arming operation; their characteristics in most cases are closely interdependent, and likewise dependent upon the characteristics of the rocket motor with which the fuze is used. In the development of the PIR fuzes the general characteristics required for these parts were first determined by trial, both in the laboratory and by static-firing tests with rocket motors. When these were roughly established certain parts were tentatively standardized; thereafter, in order to adapt the arming characteristics of a PIR fuze to a specific motor, small variations were made in the remaining parts concerned. Thus, principally for production reasons, the plug that forms the pressure chamber, the diaphragm, and the arming plunger were usually not changed. The characteristics of the parts that were varied to adapt the fuze to a specific motor became known as the "arming constants." These usually included:

- a. The diameter of the inlet orifice
- b. The diameter of the shear wire
- c. The type of inlet filter and shield

In some cases, however, it was necessary to alter additional parts.

In determining the optimum arming constants for a PIR fuze to be used with

a specific rocket motor the following practical objectives were sought :

a. To adjust the arming pressure so that at low temperatures, which correspond to minimum motor pressure, the fuze will arm. This was generally accomplished by selecting a shear wire of proper diameter to give an arming pressure 50 to 100 lb/in.² lower if possible than the minimum average motor pressure.

b. To adjust the inlet orifice so that the arming pressure is attained on the average at about the middle of the burning time. This choice of time made allowance for variations from the average partial arming time, with the purpose of insuring positive arming and at the same time permitting sufficient retardation of the gas that, should the rocket motor blow up on or just off the launcher, the resulting pressure peak would be insufficient to arm the fuze.

c. To determine what type of filtering and shielding of the inlet orifice is required.

With these objectives in mind the optimum values of the arming constants were then determined by static-firing tests in which the motor pressure, the pressure in the fuze-pressure chamber, and the arming point were recorded as functions of time, measured from ignition of the propellant. Tests were made at high, low, and medium motor temperatures, and in the case of motors with nozzle blowout disk, at a temperature (usually around 100°F) just below that at which the blowout disk was designed to function. Details of the methods used in determining the arming constants and static-firing data for the PIR-1 (Mk 146) fuze have been described in a special report.¹

Because motor pressure and burning time are strongly dependent upon temperature, usually varying by a factor of at least two between the low and high service temperature limits,² the partial arming time as determined by operation of the diaphragm is also dependent upon motor temperature. However, the variation of the partial arming time as a per cent or fraction of the total burning time of the rocket motor is not strongly dependent on temperature, and any correlation is usually marked by individual variations from other causes.

Some PIR fuzes with identical arming constants have been used, for reasons of expediency, with rocket motors having widely different characteristics. For example, the Mk 146 and Mk 157 Mods 1 and 2 fuzes, which have identical arming constants, have been used with the 2.25-in. Mk 3, the 3.25-in. Mk 7, and the 11.75-in. Mk 1 motors, which have widely different burning characteristics (Table 1, Ch. 1). This is not good practice, for the optimum arming characteristics of the fuze are achieved with none. It is a relatively straightforward matter to determine the optimum constants for a given motor, and the changes in parts required (shear wire, orifice size, etc.) are usually minor.

When the first or pressure phase of the arming process is completed about midway in the burning time, the projectile has traveled only about one-fourth the burning distance, which, in the aircraft rockets, and particularly at high temperatures, is usually only a small fraction of the 400 ft desired for the minimum arming distance of fuzes in these rockets. To delay arming still further, acceleration

¹ Mk 146 Fuze (PIR): *Static Firing Progress Report*, CIT/IIC 21, D. E. Brink, 18 March 1944.

² These limits are usually 0°F and 120°F.

forces were utilized to prevent completion of arming until after the end of burning of the rocket motor.¹ In the earlier PIR fuzes the detonator shutter was held in the *safe* position after withdrawal of the firing pin, by the inertia of the shutter itself. In later fuzes (PIR-9, PIR-19, etc.) more positive locking of the shutter was obtained by means of a setback block similar to that used in the AIR-8. Thus, the distance at which arming of the PIR fuze is completed depends on the burning distance of the rocket, which in turn depends on the temperature.

3.004. **FIRING SENSITIVITY AND DELAY.**—All of the PIR fuzes are fired by impact of the rocket, which is of sufficient intensity and duration to drive the firing pin assembly forward, compressing the anticreep or firing-pin spring, with sufficient velocity to initiate the primer of the detonator. Fuzes with a stab-type primer are inherently somewhat more sensitive than those in which a percussion type of primer is initiated directly by the firing pin. For this reason, where increased sensitivity of delay fuzes was desired, a compound detonator was used; this was initiated by a stab-type sensitive primer similar to the explosive train used in many projectile base fuzes (PIR-8, PIR-9, PIR-22).

The early PIR fuzes with delay detonator, such as the PIR-2, utilized the same shutter arrangement used in the PIR-1 instantaneous fuze. As was mentioned earlier, this proved inadequate to withstand severe impact. The PIR-12 and PIR-19 types of design were aimed chiefly at overcoming the weakness at least partially with the minimum number of design changes. In the PIR-9 and PIR-22 designs radical departures from the original shutter design were introduced, since the chief reason for beginning the development of these fuzes was to eliminate this weakness inherent in the original PIR design.

3.005. **MATERIALS.**—Most of the parts used in the early PIR fuzes were made of steel; this was due partly to the fact that a critical shortage of brass and aluminum existed at the time. Later the situation became almost reversed and aluminum alloy was considered as material for the major parts (head, body, and plug). Tests² indicated that, so far as strength was concerned, aluminum alloy performed as well as steel except in the plug. Its adoption for the head and body of the Mk 163 and Mk 164 fuzes was recommended.

3.006. **REMARKS.**—The original development of the PIR type of fuze was started early in 1942 in connection with the 1.25-in. CWG, the 7.0-in. CWR, and the 4.5-in. Barrage Rocket. These fuzes were similar and were similar in general design to the HIR-3 (Mk 140) fuze. When it became apparent that an inertia-firing base fuze was far too slow for use with these rockets the development was dropped. Aside from being armed by pressure from the rocket motor, and fired by inertia on impact, these early fuzes had little in common with the PIR designs described in the following sections. In the summer of 1943 CIT began the development of the PIR fuzes described here, for use in the aircraft rockets.

3.01. **GAS-CHECKING OF ROCKET BASE FUZES.**—One of the crucial problems that arises when a base fuze is used is that of making an effective seal between the fuze and the head, so that the hot high-pressure motor gas cannot reach the high ex-

¹ Except in the PIR-22 and PIR-12 types of fuze.

² CIT/PMC 2.82, 27 May 1945, Part 2, pp. 3-4; CIT/PMC 2.84, 24 June 1945, Part 2, pp. 6-7.

plosives of the head or the fuze. The problem of sealing the inside of the fuze itself has been considered in connection with the PIR fuze development, and only the seal between the fuze and head will be discussed here.

As is noted in 3.025, the original model of the PIR-1 fuze was designed so that the motor gas can leak only into the fuze itself, and no seal besides that in the fuze itself is necessary to prevent hot gas from reaching the high explosive in the head. However, in the PIR-1 fuze, which was standardized as the Mk 146, the design was changed so that the motor threads were no longer an integral part of the fuze head.

Thus the Mk 146 fuze and later the Mk 157 fuze were standardized on the basis of the 3.0-in. fuze-flange diameter, with a 0.020-in. unannealed copper gasket beneath it and the fuze threads appropriately luted. In the 5.0-in. AR with the 3.25-in. motor and 5.0-in. Mk 1 head a fuze adapter (CIT Drawing 5H6-12) was used. This adapter screws into the base of the head, and on the inside has the 2.750-in. fuze threads and shoulder against which the fuze seats, and the 3.25-in. threads to accommodate the motor. In the 5.0-in. HVAR with the 5.0-in. Mk 1 motor and the Mk 5 or Mk 6 head, the motor threads are on the outside of the head, and the fuze threads and shoulder are machined into the base of the head. The dimensions and details of the fuze threads and flange seating surface were essentially identical in the 5.0-in. Mk 5 and Mk 6 heads and in the inside of the fuze adapter used in the Mk 1 head.

No particular difficulty with leaks past the copper gasket had been noted with this assembly in the static firing in connection with fuze testing, but when a premature¹ occurred in field firing with HE the whole problem was extensively reinvestigated.² The main points brought out in this investigation were (1) that to prevent leaks it was necessary to exercise considerable care in manufacture and inspection of the metal parts and assembly, and (2) that a direct leak to the TNT filler readily gave prematures, but that sizable leaks past a poor seal could occur without ignition of the TNT, even when the leak produced pressure inside the head sufficient to prevent fuze arming. This latter fact emphasized the necessity for static-firing tests to demonstrate the efficiency of any gas seal. Further tests³ suggested the mechanism by which leaks occurred with various gasket materials, but did not offer any alternative to the necessity for care in manufacture and inspection of the components involved in the seal, and in particular in the assembly of the fuze and gasket into the head. The fact that there is no way by which inspection can detect a bad assembly after it is made is perhaps the worst characteristic of seals of this type, and the poor quality which often characterized production parts, particularly the gasket seating surface itself, indicated the unsatisfactory nature of the design.

¹ It may happen that the high explosive in a round of ammunition (or bomb) detonates after the propelling charge has been ignited (or bomb has been dropped), but before the desired or proper time or point of detonation. Such behavior is generally referred to as an air burst or premature detonation, or simply as a "premature."

² CIT/PMC 2.49, 10 September 1944, Part 2, pp. 1-6.

³ CIT/PMC 2.53, 8 October 1944, Part 2, pp. 4-10.

As an obvious alternative, gas seals of the type used in gun projectiles were extensively investigated;¹ in these a combination lead-copper "gas check" is forced into a triangular groove, the sides of the triangle being the edges of the rocket head and the fuze head respectively.

The general conclusions were that gas checks of the narrow type normally used to seal fuzes in the base adapters (similar to that used in the 5.0-in. Mk 8-0 rocket head) were perfectly satisfactory, provided they were properly assembled, with a sufficient applied load when the gas check is crimped in place. Furthermore, the gas-check type of seal was found to be satisfactory even when poorly assembled, or assembled with bad parts having scratched or gouged seating surfaces or threads not at right angles to the flange seating surfaces. The condition of the gas check as seen on a visual inspection was, within limits, a satisfactory criterion of the effectiveness of the sealing. The PIR fuzes utilizing gas checks were assembled in the heads with a rubber gasket between the shoulder of the fuze and the projectile. Since the gasket was always found to be badly cut up and torn on assembly, and offered no additional sealing protection whatever, its discontinuance was recommended.

The sealing of the base adapter into a projectile is also accomplished with a gas check of the lead-copper type, but in many cases these are much thicker and heavier than those used to seal a fuze or the base adapter of the 5.0-in. Mk 8-0 rocket head, and greater loads in the crimping operation are necessary to provide effective sealing.

A series of 20 test fixtures for each type (light and heavy) were sent to NAD, Mare Island, where they were assembled both with and without rubber gaskets and the gas checks crimped under the standard loading plant conditions. None was found to leak when tested by static firing.

In current production all rocket base fuzes are sealed in the heads with the projectile type of gas check, except the Mk 165 fuze, which is specifically for the 3.25-in. motor and 5.0-in. Mk 1 head. In this case the fuze head contains the motor threads, and is thus a one-piece combination of the fuze head and adapter exactly like the early PIR-1 design.

¹ CIT/PMC 2.53, 8 October 1944, Part 2, pp. 11-14; CIT/PMC 2.58, 12 November 1944, Part 2, pp. 5-13.

3.02. PIR-1 (Mk 146) FUZE

Rockets in which used

5.0-in. Aircraft Rocket, with 3.25-in. Motor Mk 7 and 5.0-in. Head Mk 1

7.2-in. Demolition Rocket, with 2.25-in. Motor Mk 3 and 7.2-in. Head Mk 10

Dimensions and weight

Over-all length: 6.17 in.

Thread: 2.75"-14NS

Weight: 3.15 lb

Explosive components

Detonator: Mk 24 (for Mk 146 Mod 0 fuze)

Sensitive primer from Mk 19 fuze, and Mk 23 detonator (for Mk 146 Mod 1 fuze)

(Both detonators instantaneous)

Lead-in: tetryl

Booster: tetryl (12 gm)

General arrangement drawing

Mk 146 Mod 0: BuOrd Drawing No. 393777

Mk 146 Mod 1: BuOrd Drawing No. 438182

3.021. GENERAL.—The PIR-1 (Mk 146) fuze was developed primarily for use in the 5.0-in. Aircraft Rocket. Almost simultaneously the requirement arose for a base fuze for the 7.2-in. Demolition Rocket. Although these two rockets are completely dissimilar both in characteristics and in tactical use, both required base detonation with a slight delay on impact. The PIR-1 fuze was therefore standardized as the Mk 146 for use in both the 5.0-in. AR and the 7.2-in. DR.

In the 5.0-in. AR it was desired to use the Mk 146 in conjunction with a selectively armed nose fuze (Mk 148 or Mk 149) to detonate the rocket head after penetration of the target. In the 7.2-in. DR, whose original tactical use was in firing from tanks for destruction of concrete walls at close range, a very slight delay in firing after impact was desired to permit distortion of the light-walled head and spreading of the plastic explosive prior to detonation.

Safety requirements for the two rockets were generally similar, except that in the aircraft rocket emphasis was placed on obtaining a long arming distance, whereas in the demolition rocket a short arming distance to permit very close range work was desired. Fortunately, the burning distances of the two rockets are such as to give acceptable values of the arming distance for both.

3.022. DESCRIPTION.—The fuze head screws into an adapter fixed in the base of the rocket head. In the 5.0-in. Mk 1 head the fuze body extends into a cavity drilled for it in the TNT filler of the head. In the 7.2-in. Mk 10 head a fuze seat liner containing an auxiliary booster separates the fuze body from the filler. A copper gasket on which the flange of the fuze head seats is intended to provide a gastight seal between the rocket motor and the interior of the head. The rear end of the fuze (exterior surface of the plug) is exposed to the front end of the rocket motor. The fuze is normally shipped installed in the base of the head and is not removed or serviced thereafter.

When the fuze is assembled in the *unarmed* position the lightweight aluminum alloy arming plunger is held in position by the shear wire. The arming plunger retains the locking ball, which in turn locks the firing-pin body to the fuze body in such a position that the firing pin, extending through the firing-pin guide, engages and holds the shutter so that the detonator is out of line with the booster lead-in. The fuze is thus "detonator-safe." Further details of design and operation are discussed in the paragraphs on arming and firing.

3.023. **ARMING.**—The fuze arms in two stages:

1. Gas from the rocket motor, at a pressure ranging from 300 to 1600 lb/in.² for the 3.25-in. Mk 7 motor, enters the pressure chamber in the head of the fuze through a small orifice in the inlet screw. Motor closure disks are deflected by the inlet shield, and debris from the rocket motor is filtered out by the inlet filter. The small orifice for entrance of gas delays the build-up of the pressure until approximately half the burning time has passed. Then, when the pressure in the chamber reaches a value of about 290 lb/in.², the diaphragm collapses, severing the shear wire, and forcing the arming plunger down. Movement of the plunger releases the locking ball, which, in the unarmed condition, locks the firing-pin body in place; this allows the firing-pin body to move toward the rear under its own inertial force, due to acceleration, and the force of the firing-pin spring. The firing pin, which is attached to the firing-pin body, is thus withdrawn from the detonator shutter, which it normally locks in the *safe* position.

2. When the rocket accelerates, inertia forces the shutter back against the firing-pin guide, compressing the shutter spring and engaging the shutter-locking pin in a hole in the firing-pin guide. About midway during acceleration the firing pin is withdrawn from the shutter, but the shutter, held by the locking pin, remains locked in the *safe* position. When acceleration ceases, the shutter spring forces the shutter forward against the lead-in disk and disengages the shutter-locking pin from the hole in the firing-pin guide. The shutter spring then swings the shutter into the *armed* position (detonator in line with firing pin and lead-in), where it is locked by the detent.

Because of the delay in admission of gas from the rocket motor to the pressure chamber, the first stage in arming does not occur until approximately half the burning is over; thus, if the rocket motor blows up before it leaves the launcher, this delay should prevent arming of the fuze. A minimum acceleration of 9 *g* is required to accomplish the shutter delay in the second stage of arming.

Arming is not completed until after the end of acceleration. The burning distance and therefore the arming distance will vary with the temperature. On the average, arming is completed within 0.1 sec after the end of burning. Approximate arming distances observed for the 5.0-in. AR and calculated for the 7.2-in. DR are tabulated below.

Temperature.....	<i>Arming Distance</i>		
	0°F	70°F	135°F
5.0-in. AR (3.25-in. Mk 7 motor).....	575 ft	350 ft	250 ft
7.2-in. DR (2.25-in. Mk 3 motor).....	65 ft	50 ft	35 ft

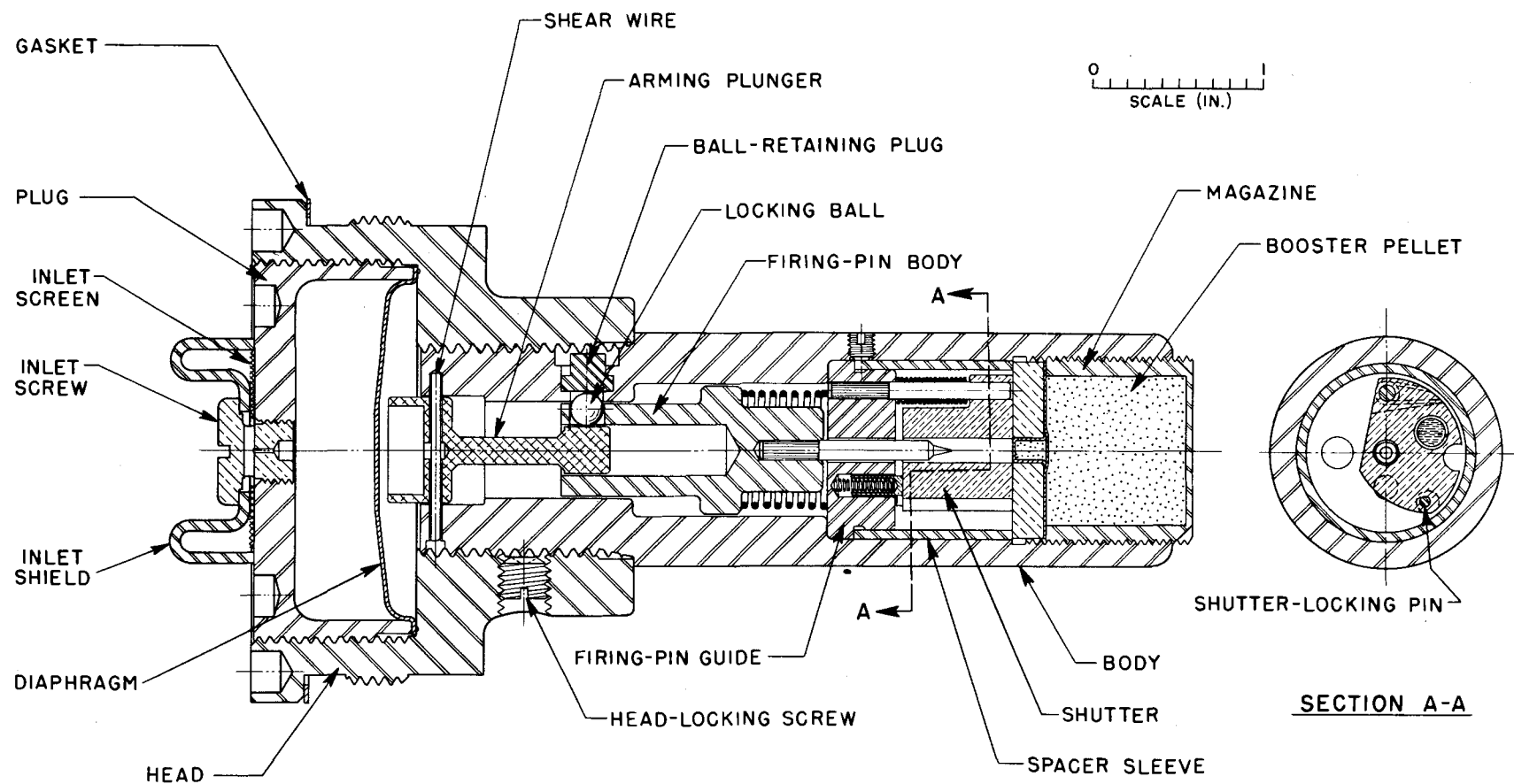
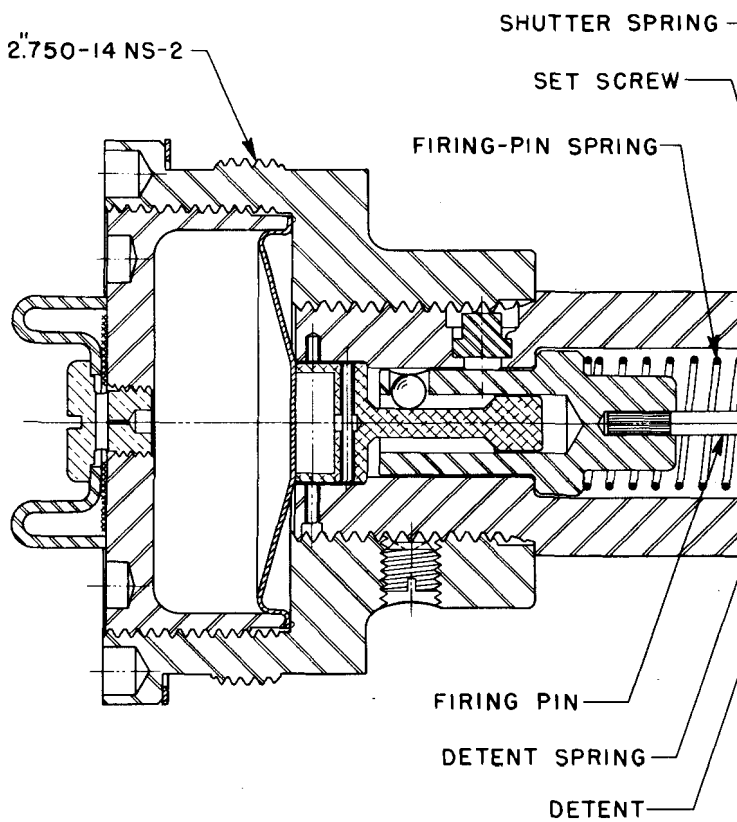


FIG. 44. PIR-1 fuze, unarmed (Base Fuze Mk 146).



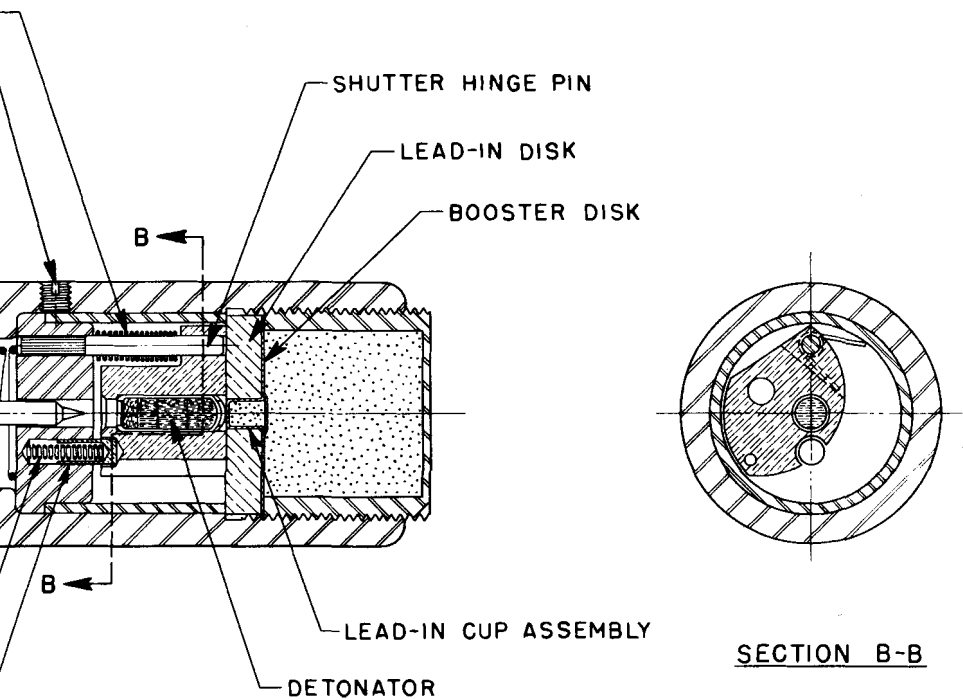


FIG. 45. PIR-1 fuze, armed.

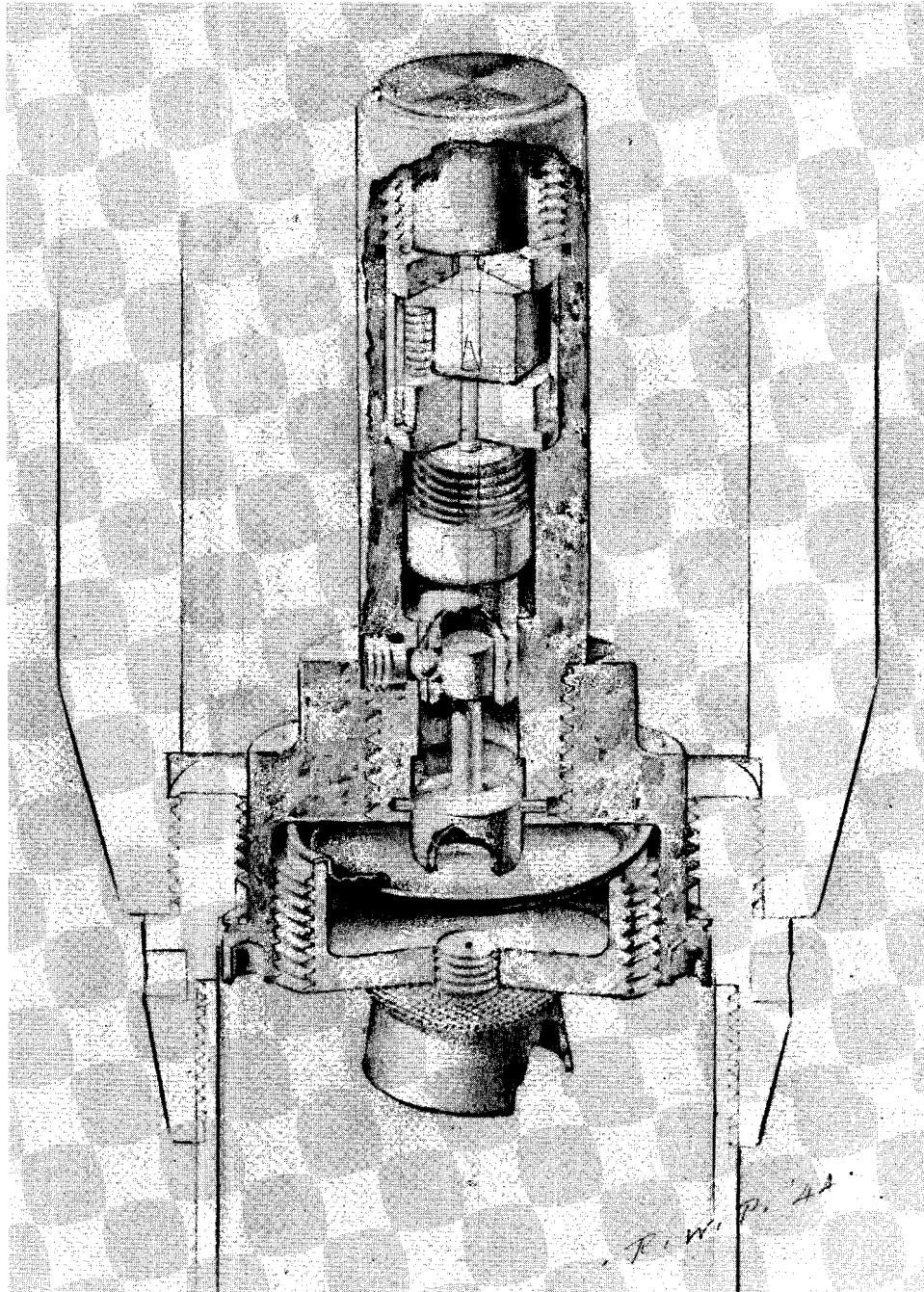


FIG. 46. PIR-1 fuze (Base Fuze Mk 146), unarmed, assembled in the base of the 5.0-in. Head Mk 1.

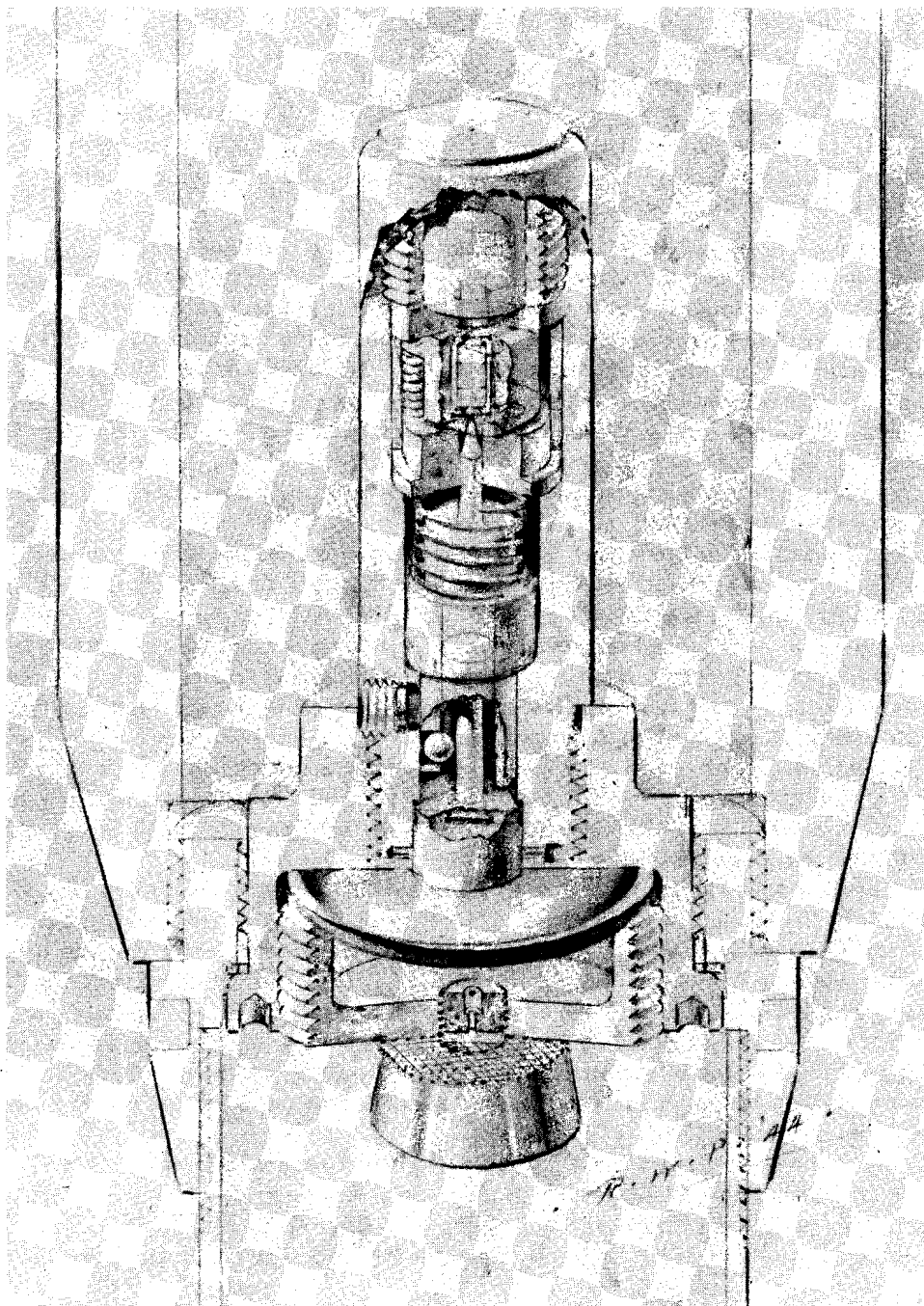


FIG. 47. PIR-1 fuze (Base Fuze Mk 146), armed, assembled in the base of the 5.0-in. Head Mk 1.

The arming constants of the Mk 146 fuze, defined and discussed in 3.003, Item 8, are as follows:

1. Diameter of inlet orifice.....0.018 in.
2. Diameter of shear wire.....0.051 in. (Mk 146 Mod 0)
0.057 in. (Mk 146 Mod 1)
3. Diaphragm.....0.020-in.-thick copper
4. Inlet shield and inlet filter

3.024. FIRING.—The fuze fires on impact when the inertia of the firing-pin body drives the pointed firing pin forward into the primer of the instantaneous detonator. The detonator initiates the tetryl lead-in and tetryl booster.

The only delay in firing after impact is that inherent in the motion of the firing pin about 0.19 in. forward to strike the primer. The time required for this is dependent upon the type of impact sustained by the round. Tests of ground-launched 5.0-in. AR rounds with Mk 146 fuzes¹ indicated that for light plate ($\frac{1}{4}$ in. in thickness) this delay might be as long as 0.008 or 0.010 sec, whereas for heavier plate it was less than 0.001 sec and the head detonated in or on the face of the plate, depending on its thickness.

In the 5.0-in. AR the fuze is sufficiently sensitive to function fairly consistently on $\frac{1}{4}$ -in. mild steel plate. On water impact the fuze will function reliably only if a flat shipping plug is used in the nose of the 5.0-in. Mk 1 head.² With a conical nose plug the side forces on impact tend to break up the round and are apparently too great to permit the firing pin to move forward. In the 7.2-in. DR the Mk 146 fuze functions on both ground and water impacts, but does not function consistently at very low impact angles.

3.025. REMARKS.—The Mk 146 fuze was standardized for use in both the 5.0-in. AR and the 7.2-in. DR. About 44,000 Mk 146 Mod 0 fuzes were manufactured by CIT; about 12,000 of these were delivered to the Army for use in the 7.2-in. DR, and the remainder to the Navy for use in the 5.0-in. AR.

Service use of the 5.0-in. AR soon indicated that a longer delay than that inherent in the Mk 146 was necessary in order to obtain the desired penetration of targets (principally shipping) before detonation. For this reason the Mk 146 fuze in the 5.0-in. AR was replaced by the Mk 157 (PIR-2), which contained a fixed delay element of 0.02 sec in the detonator. Aside from its lack of a long delay action the Mk 146 appears to have given generally satisfactory performance in the 5.0-in. AR. Because of the instantaneous detonator, the weakness inherent in the shutter design on heavy oblique impact did not become apparent in the Mk 146 as it did in the Mk 157 (PIR-2) fuze.

Service tests indicated generally satisfactory performance of the Mk 146 fuze in the 7.2-in. DR, although tests by the Army Engineer Board showed that a delay slightly greater than that inherent in the motion of the firing pin would have been beneficial (see 3.08 and 3.11). Since the Mk 146 fuze continued to be used

¹ CIT/PMC 2.19, 13 February 1944, Part 2, pp. 3-5; CIT/PMC 2.26, 2 April 1944, Part 2, pp. 4-6.

² CIT/PMC 2.20, 20 February 1944, Part 1, pp. 4-5; CIT/PMC 2.25, 26 March 1944, Part 2, pp. 7-8; CIT/PMC 2.30, 30 April 1944, Part 1, pp. 4-5.

in the 7.2-in. DR after it was replaced in the 5.0-in. AR by the Mk 157, it was intended by the Bureau of Ordnance to improve the gas checking in the 7.2-in. DR by adopting an integral fuze head and base fuze-to-motor adapter, as used in the Mk 160 and Mk 165 (PIR-21), to the Mk 146 fuze. This modification was designated the Mk 161 fuze and except for the fuze head was identical with the Mk 146 Mod 1 fuze; the Mk 161, however, was never issued for service use. It is worth noting that the original design of the PIR-1 fuze (prior to standardization) had an integral fuze head and base fuze adapter similar to that of the Mk 160, Mk 161, and Mk 165 (PIR-21) fuzes.

The Mk 146 Mod 1 fuze differed from the Mk 146 Mod 0 principally in being more sensitive; this was accomplished by changing the detonator to include the sensitive primer used in the Mk 19 and other projectile base fuzes. Since this addition necessitated reducing the length of the detonator, the shorter detonator from the Mk 137 fuze was adopted. In addition, because of failures of the Mk 146 fuze in drop tests, the diameter of the shear wire was increased from 0.051 in. to 0.057 in. This change increased the arming pressure from an average of 250 lb/in.² to about 290 lb/in.²

Because the Mk 146 fuze was designed for use with both the 3.25-in. Mk 7 and the 2.25-in. Mk 3 motors, and because the burning characteristics of these motors are quite different (see Table 1, Ch. 1), the fuze does not have the optimum arming characteristics for either motor. Improvement for use with the 2.25-in. Mk 3 motor only would be made by increasing the strength of the shear wire and the diameter of the inlet orifice. For use with the 3.25-in. Mk 7 motor only a greater delay in partial arming could safely be obtained by reducing the diameter of the inlet orifice.

3.03. PIR-2 (Mk 157) FUZE

Rockets in which used

Mk 157 Mod 0 in 5.0-in. AR; 3.25-in. Motor Mk 7 and 5.0-in. Head Mk 1
Mk 157 Mod 1 in 11.75-in. AR; 11.75-in. Motor Mk 1 and 11.75-in. Head Mk 1
Mk 157 Mod 2 in 11.75-in. AR; 11.75-in. Motor Mk 1 and 11.75-in. Head Mk 2

Dimensions and weight

Mk 157 Mod 0 and Mod 1 same as Mk 146 fuze; Mk 157 Mod 2 has wide flange on head and projectile type of gas check

Explosive components

Detonator: adapted from delay-detonator assembly of Mk 145 fuze (0.020-sec delay)

Lead-in: from Mk 146 fuze

Booster: from Mk 146 fuze

General arrangement drawings

Mk 157 Mod 0: BuOrd Drawing No. 489015

Mk 157 Mod 1: BuOrd Drawing No. 439629

Mk 157 Mod 2: BuOrd Drawing No. 439630

3.031. GENERAL.—As mentioned in 3.025, the firing delay after impact inherent in the Mk 146 fuze proved insufficient to give the 5.0-in. AR the desired target penetration before detonating, and therefore a base fuze with a short fixed pyrotechnic delay was indicated. When the PIR-1 (Mk 146) fuze was designed the possibility was recognized that a delay detonator might be required; accordingly, the fuze was so designed that the 0.02-sec delay-detonator assembly from the Nose Fuze Mk 145, described in 2.025, p. 28, could be incorporated with only minor design and dimensional changes. This modification of the PIR-1 containing a delay detonator was designated the PIR-2 fuze and was later standardized by the Navy for use in the 5.0-in. AR as the Mk 157 Mod 0 fuze. Modifications of the PIR-2 used in the 11.75-in. AR were designated the Mk 157 Mod 1 and Mod 2 fuzes.

Preliminary tests of the PIR-2 fuze for functioning on plate and concrete impacts were performed in conjunction with the development of the PIR-1 fuze.¹

Unfortunately these tests were not extensive enough nor were the test facilities adequate² to reveal the degree of weakness inherent in the PIR-2 shutter design when a delay detonator was used (see comments under 3.035, p. 108).

3.032. DESCRIPTION.—Three fuzes of the PIR-2 type were standardized and issued:³

¹ CIT/PMC 2.26, 2 April 1944, Part 2, pp. 4-6; CIT/PMC 2.28, 16 April 1944, Part 1, pp. 3-5; CIT/PMC 2.35, 4 June 1944, Part 2, pp. 13-17; CIT/PMC 2.36, 11 June 1944, Part 2, pp. 15-17.

² CIT/PMC 2.38, 25 June 1944, Part 2, p. 3.

³ A fourth fuze, the Mk 160, was never produced for issue. It was identical with the Mk 157 Mod 0 but had an integral fuze head and base fuze adapter as later used in the Mk 165 (see 3.15). The Mk 165 fuze was produced in place of the Mk 160.

1. **Mk 157 MOD 0.**—This fuze, used in the 5.0-in. AR, is identical with the PIR-1 (Mk 146) except for the following differences, all associated with the use of the delay detonator in the Mk 157 fuze:

a. A delay-detonator assembly with a 0.020-sec delay element similar to that used in the Mk 145 fuze is used, and appropriate modifications in the shutter are made.

b. Since the delay detonator has a percussion primer, the stab-type firing pin of the Mk 146 fuze is replaced by a firing pin with a rounded point. Since it must not puncture the cover of the percussion primer,¹ the firing pin is made to shoulder against the face of the detonator case with the point extending the proper distance into the primer. To avoid crushing of the detonator case by the weight of both the firing pin and firing-pin body on heavy impact, the firing pin and firing-pin body are assembled in such a way that on heavy impact the inertia of the firing-pin body shears a lock wire holding the parts together, and the two parts telescope.

2. **Mk 157 MOD 1.**—This fuze, used in the 11.75-AR with the 11.75-in. Mk 1 head, is identical with the Mk 157 Mod 0 except that for additional strength (a) the fuze head and body are of pearlitic manganese steel, and (b) the 2.75-in. diameter threads on the fuze head extend the full length of the head.

3. **Mk 157 MOD 2.**—This fuze replaced the Mk 157 Mod 1 in the 11.75-in. Mk 2 head. The only difference is that the Mk 157 Mod 2 is sealed in the base plug of the head by a 3.2-in. diameter projectile-type gas check, instead of by a copper gasket under the fuze-head flange.

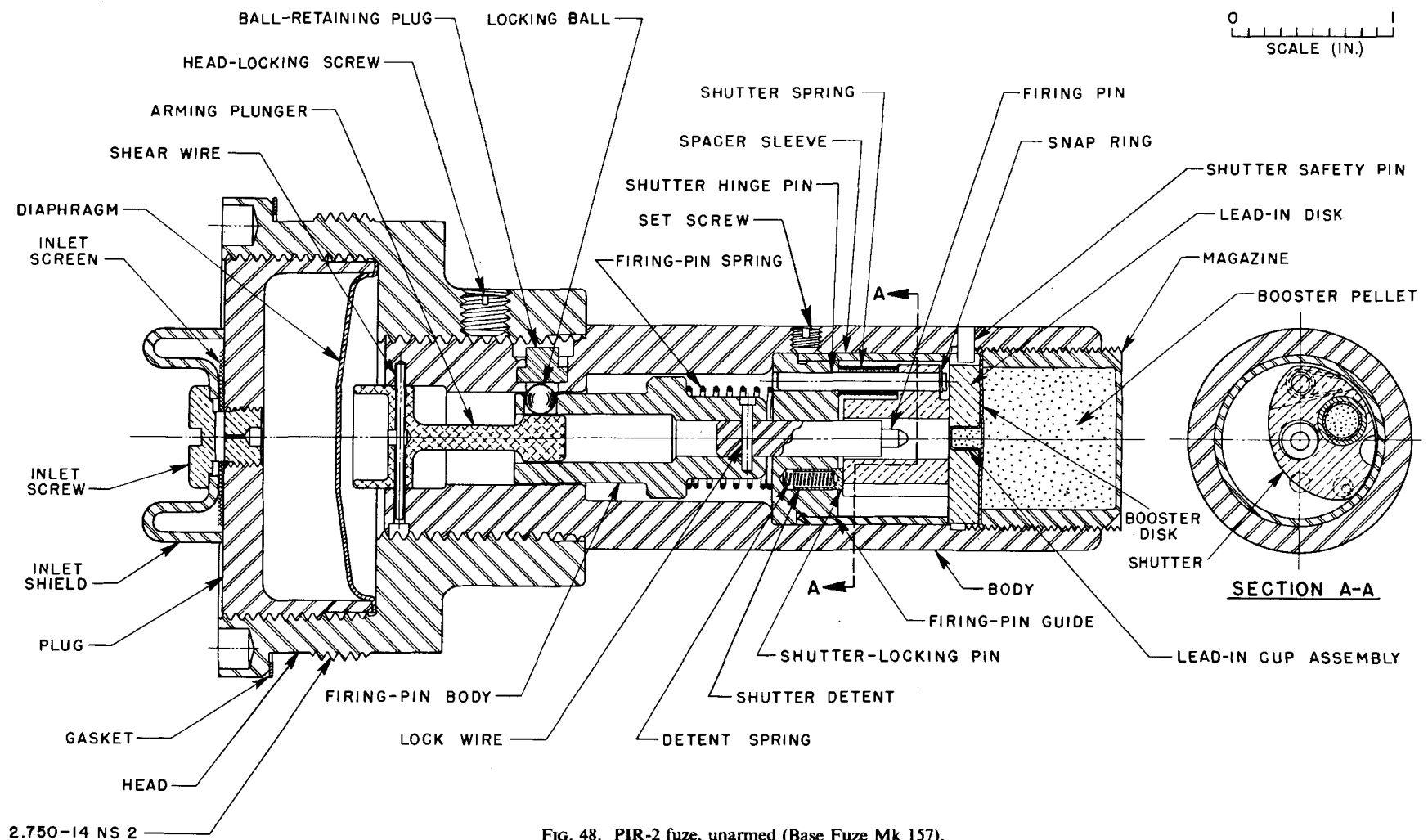
3.033. **ARMING.**—The arming operation and the arming constants of all mods of the Mk 157 fuze are identical with those of the Mk 146.

In the 11.75-in. AR partial arming, because of the characteristics of the 11.75-in. motor (Table 1, Ch. 1), occurs at 25 per cent of the burning time. Complete arming in this rocket is accomplished at calculated distances of between 300 and 670 ft, depending on the temperature.

3.034. **FIRING.**—The Mk 157 fuzes are fired by the inertia of firing-pin body driving the firing pin forward against the primer of the delay detonator at impact. On heavy impact the inertia of the firing-pin body severs the lock wire connecting the firing-pin body and firing pin, and the two parts telescope; this prevents crushing of the detonator case. The detonator contains a fixed pyrotechnic (black powder) delay element of 0.020 sec, in addition to which there is added the slight delay inherent in the motion of the firing pin on impact. The lead azide relay detonator in the base of the detonator assembly initiates the tetryl lead-in and the booster charge.

Because the percussion primer is less sensitive than the stab-type sensitive primer, the Mk 157 fuze is less sensitive than the Mk 146. Tests of the Mk 157 fuze against plate indicated that functioning on plate targets less than $\frac{1}{2}$ in. in thickness is unreliable.

¹ A punctured primer cover relieves the gas pressure from the firing of the primer, with the result that the delay element may not be ignited, or if ignited burns slowly, giving an abnormally long delay or sometimes a low-order detonation of the relay detonator.



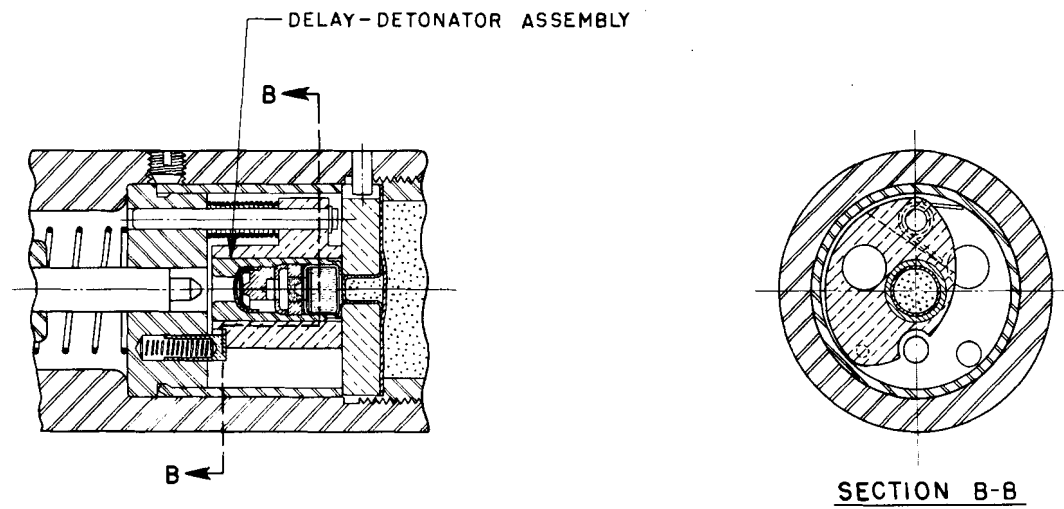


FIG. 49. Sections of PIR-2 fuze shown in Fig. 48, armed.

3.035. REMARKS.—Development of the PIR-2 fuze was started in February, 1944, and 6000 Mk 157 Mod 0 fuzes were manufactured by CIT for service tests by the Navy in April and May, 1944. In July, 1700 Mk 157 Mod 0 fuzes were manufactured for service test by the AAF in the 5.0-in. HVAR. After standardization of the Mk 157 Mod 0 in the 5.0-in. AR, a total of 96,000 Mk 146 Mod 1 fuzes of BuOrd production were converted to Mk 157 Mod 0 fuzes by CIT between October, 1944 and March, 1945 to replace Mk 146 fuzes in the 5.0-in. AR.

Mk 157 fuzes manufactured by CIT differed from those manufactured by the Bureau of Ordnance by using the detonator from the Mk 145; in the BuOrd fuzes a similar detonator in a slightly longer detonator case was used. There were also minor differences in associated parts.

Extensive testing of the Mk 157 fuzes in the aircraft rockets revealed that a large percentage of duds and low orders occurred, particularly on heavy oblique impacts.¹ These were found to be due mainly to the fact that the shutter was often knocked out of the *armed* position by this type of impact, often shearing the detent and hinge pin. The firing pin usually struck the primer and initiated it before this deformation occurred, but by the time the delay element had burned through and initiated the relay detonator the shutter had been forced into such a position that the detonator was no longer aligned with the lead-in. If the malalignment of detonator and lead-in was only partial a low order of detonation of the lead-in and the remainder of the explosive train usually resulted. If the detonator was entirely out of line with the lead-in, that is, the shutter knocked back to *safe* position, the lead-in was not initiated and the round became a dud. This shortcoming was largely overcome by the design changes introduced in the Mk 163 (PIR-19) and Mk 165 (PIR-21) fuzes, which later replaced the Mk 157 Mod 2 and the Mk 157 Mod 0 in the 11.75-in. AR and 5.0-in. AR respectively.

¹ See, for example, CIT/PMC 2.60, 26 November 1944, Part 2, p. 4.

3.04. PIR-3 (Mk 159) FUZE

Rocket in which used

5.0-in. High-Velocity Aircraft Rocket, with 5.0-in. Motor Mk 1 and 5.0-in. Head Mk 6

General arrangement drawing

Mk 159 Mod 0: BuOrd Drawing No. 422550

Mk 159 Mod 1: BuOrd Drawing No. 439631

3.041. GENERAL.—The PIR-3 fuze, standardized as the Mk 159 Mod 0, is a modification of the Mk 157 (PIR-2) fuze for use in the 5.0-in. HVAR with the 5.0-in. Mk 6 head. It is essentially identical with the Mk 157 Mod 1 fuze, with the following exceptions:

1. ARMING.—The arming constants, listed below, are adjusted to the burning characteristics of the 5.0-in. Mk 1 motor:

- a. Diameter of inlet orifice. 0.018 in.
- b. Diameter of shear wire. 0.064 in.
- c. Grooved inlet washer

2. FIRING.—Because of the higher velocity of the 5.0-in. HVAR as compared with the 5.0-in. AR, a shorter delay element of 0.015 sec is used in the detonator of the Mk 159.

The Mk 159 Mod 0 is sealed in the head by a copper gasket under the fuze-head flange. In the Mk 159 Mod 1 the flange is increased to 3.2 in. in diameter and a projectile-type gas check is used (the same fuze head and gas check as in the Mk 157 Mod 2).

3.042. REMARKS.—The Mk 159 fuze has the same shutter design as the Mk 157, and as a consequence at heavy oblique impact it suffered from the same difficulties as the Mk 157 fuze; the Mk 159 was therefore replaced by the Mk 164 (PIR-20) fuze.

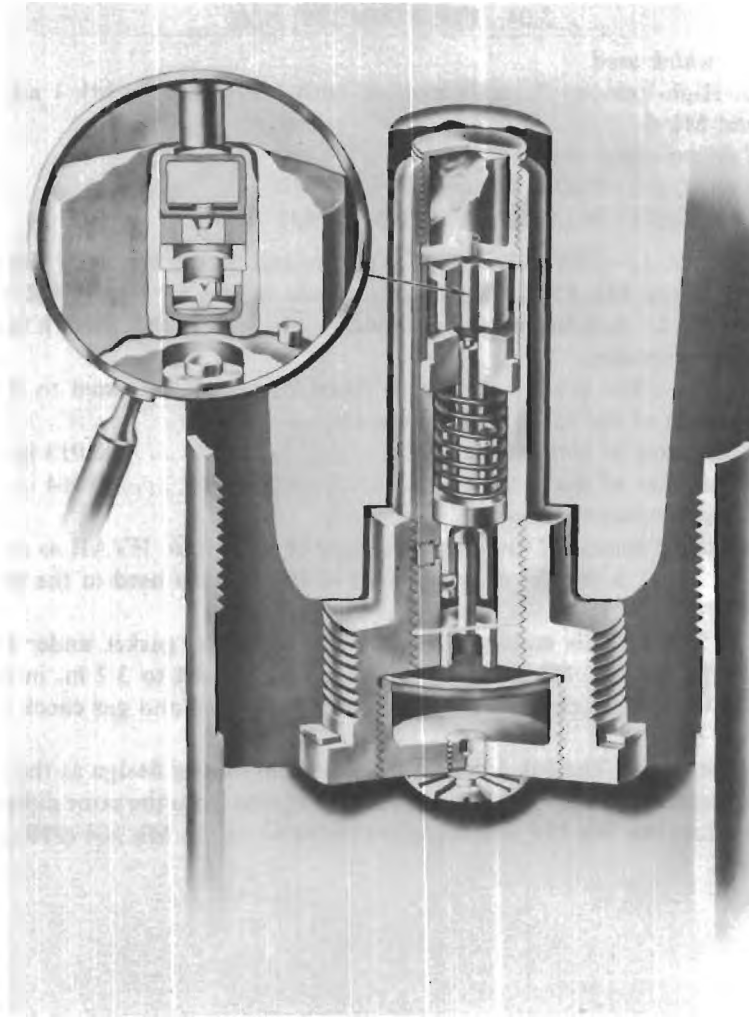


FIG. 50. PIR-3 fuze (Base Fuze Mk 159), armed, assembled in base of 5.0-in. Head Mk 5 Mod 1 or Mk 6 Mod 0.

3.05. PIR-4 FUZE

Rocket in which used

Army 4.5-in. T22 Motor

General arrangement drawing

CIT Drawing No. R2b-01

3.051. GENERAL.—The PIR-4 fuze is a modification of the Mk 146 Mod 1 fuze adapted for use with rockets propelled by the Army 4.5-in. T22 motor. The PIR-4 is identical with the Mk 146 Mod 1 fuze with the exception of certain arming constants, which are listed below:

1. Diameter of inlet orifice.....0.033 in.
2. Diameter of shear wire.....0.064 in.
3. Grooved inlet washer
4. Solid head arming plunger

These constants were determined by static-firing tests with the T22 motor.¹ The characteristics of the motor (Table 1, Ch. 1) are quite different from those of CIT motors; its burning time is very short and its operating pressure high by comparison. Furthermore, because the tubing used in this motor is made to withstand very high pressure, it was necessary to provide strength in the fuze diaphragm for a possible pressure as high as 8000 lb/in.² For this reason the head of the arming plunger was made solid to give a solid seat for the diaphragm and prevent it from punching through, if the pressure should rise to a very high value in the pressure chamber.

3.052. REMARKS.—Five hundred Mk 146 Mod 1 fuzes were converted into PIR-4 fuzes by CIT and delivered to the Army Ordnance Department for tests in a demolition rocket using the 4.5-in. T22 motor.

¹ CIT/PMC 2.37, 18 June 1944, Part 1, p. 3.

3.06. PIR-5 FUZE

Rocket in which used

11.75-in. Aircraft Rocket, with 11.75-in. Motor Mk 1 and 11.75-in. Head Mk 1

General arrangement drawing

CIT Drawing No. R3b-01

3.061. GENERAL.—The PIR-5 fuze is a modification of the Mk 157 Mod 1 fuze for use in the 11.75-in. AR. The PIR-5 fuze is identical with the Mk 157 Mod 1 except for the arming constants, which are as follows:¹

1. Diameter of inlet orifice.....0.0145 in.
2. Diameter of shear wire..... 0.064 in.
3. Inlet shield and inlet filter

3.062. REMARKS.—The PIR-5 was developed to replace the Mk 157 Mod 1 in the 11.75-in. AR, because the arming constants of the Mk 157 Mod 1 (identical with those of the Mk 146) were far from the optimum values for the 11.75-in. motor. In the PIR-5 the partial arming time was increased to about 50 per cent of the burning time as compared with 25 per cent for the Mk 157 Mod 1, which provided greater safety against arming of the fuze in event of a motor failure occurring early in burning.

The PIR-5 was never standardized as such, but its arming constants were later adopted for the Mk 163 Mod 1 (PIR-19) fuze, which replaced the Mk 157 Mod 1 and Mod 2 in the 11.75-in. AR.

¹ CIT/PMC 2.55, 22 October 1944, Part 2, pp. 3-6; CIT/PMC 2.59, 19 November 1944, Part 2, p. 21.

3.07. PIR-6 FUZE

Rocket in which used

Fast-burning 7.2-in. Demolition Rocket, with 2.25-in. CIT Motor Model 14 and 7.2-in. Head Mk 10

General arrangement drawing

CIT Drawing No. R2c-01

3.071. GENERAL.—The PIR-6 fuze is a modification of the Mk 146 Mod 1 fuze for use in the fast-burning 7.2-in. DR. This rocket was developed for test by the Army Engineer Board in an effort to reduce the dispersion of the 7.2-in. DR. Because the characteristics of the 2.25-in. Model 14 motor are quite different from those of the 2.25-in. Mk 3 motor used in the standard 7.2-in. DR (see Table 1, Ch. 1), it was necessary to alter the arming constants of the Mk 146 (PIR-1) fuze. The PIR-6 is identical with the Mk 146 Mod 1 fuze in all respects except the arming constants, which are listed herewith:

1. Diameter of inlet orifice.....0.021 in.
2. Diameter of shear wire.....0.051 in.
3. Inlet shield and filter

3.072. REMARKS.—A number of PIR-6 fuzes were supplied to the Army Engineer Board for test in the fast-burning 7.2-in. DR. This rocket, and consequently the fuze, were not standardized for production.

3.08. PIR-7 FUZE

Rocket in which used

Same as PIR-6 fuze

General arrangement drawing

CIT Drawing No. R3c-01

3.081. GENERAL.—The PIR-7 fuze, a companion of the PIR-6, is a modification of the Mk 157 Mod 0 (PIR-2) fuze for use in the fast-burning 7.2-in. DR.

Tests of various PIR fuzes in demolition rockets made by the Army Engineer Board had indicated the desirability of a short fixed firing delay for maximum effectiveness of this type of rocket against concrete obstructions. Tests had shown that the optimum delay (approximately 5 milliseconds) was longer than that obtained with the Mk 146 fuze (no delay) and shorter than that given by the Mk 157 fuze (0.02 sec). For further tests the Naval Ordnance Laboratory supplied a quantity of delay-detonator assemblies, of the type used in the Mk 145 fuze, specially loaded with a 0.010-sec delay element, which was regarded as the minimum practicable in this detonator design. The PIR-7 fuze is thus a modification of the Mk 157 Mod 0 fuze that has the arming constants of the PIR-6 fuze and a special 0.010-sec delay.

3.082. REMARKS.—A number of PIR-7 fuzes were supplied to the Army Engineer Board for test in the fast-burning 7.2-in. DR for comparison of their effectiveness with PIR-6 fuzes.

3.09. PIR-8 FUZE

Rocket in which used

Fast-burning 100-ft-range 7.2-in. Demolition Rocket, with 2.25-in. CIT Motor Model 15 and 7.2-in. Head Mk 10

General arrangement drawing

CIT Drawing No. R3d-01

3.091. GENERAL.—The PIR-8 fuze is a modification of the PIR-2 fuze for use in the fast-burning 100-ft-range 7.2-in. DR.

The contemplated tactical use of this rocket was to detonate underwater mines in landing operations; this called for a fuze to be initiated on water impact and to fire with delay after the round had entered the water. Because the impact velocity of this rocket is so low (Table 1, Ch. 1), a sensitivity greater than that inherent in the PIR-2 fuze was required to obtain functioning on water impact. To attain the maximum sensitivity possible in the PIR design without radical modification, a stab-type sensitive primer was used to initiate the delay detonator. The alterations in the PIR-2 design are described below.

3.092. DESCRIPTION.—The PIR-8 fuze is essentially a modification of the PIR-2, with the following major changes:

1. ARMING.—The arming constants are adjusted for optimum performance with the 2.25-in. Model 15 motor; they are as follows:

- a. Diameter of inlet orifice 0.032 in.
- b. Diameter of shear wire 0.072 in.
- c. Diaphragm¹ 0.025-in. brass
- d. Inlet shield and filter

2. FIRING.—The following features were introduced:

- a. An extremely weak anticreep spring to increase the sensitivity
- b. A special thick shutter, similar in design to the Mk 157 shutter but omitting the shutter-locking pin and containing:
 1. The sensitive primer from the Mk 19 fuze
 2. A delay-element firing pin similar to that used in projectile base fuzes
 3. The Mk 145 fuze 0.02-sec delay detonator
- c. A stab-type (Mk 146) firing pin
- d. To maintain the fuze at the same over-all length as the Mk 146 and Mk 157 a special short booster pellet was used to compensate for the increase in thickness of the shutter.

3.093. REMARKS.—Tests indicated that functioning of the PIR-8 fuze on water impact was a borderline affair,² and it was also recognized that the 0.02-sec delay provided by the Mk 145 fuze detonator was too short for the purpose. However, a number of fuzes were supplied to the Army Engineer Board for test in the short-range demolition rocket. This rocket was not standardized for production.

¹ With a shear wire greater than 0.064 in. in diameter the standard 0.020-in.-thick copper diaphragm used in most PIR fuzes is not stiff enough to operate the arming plunger.

² CIT/PMC 2.51, 24 September 1944, Part 1; CIT/PMC 2.58, 12 November 1944, Part 1, p. 1.

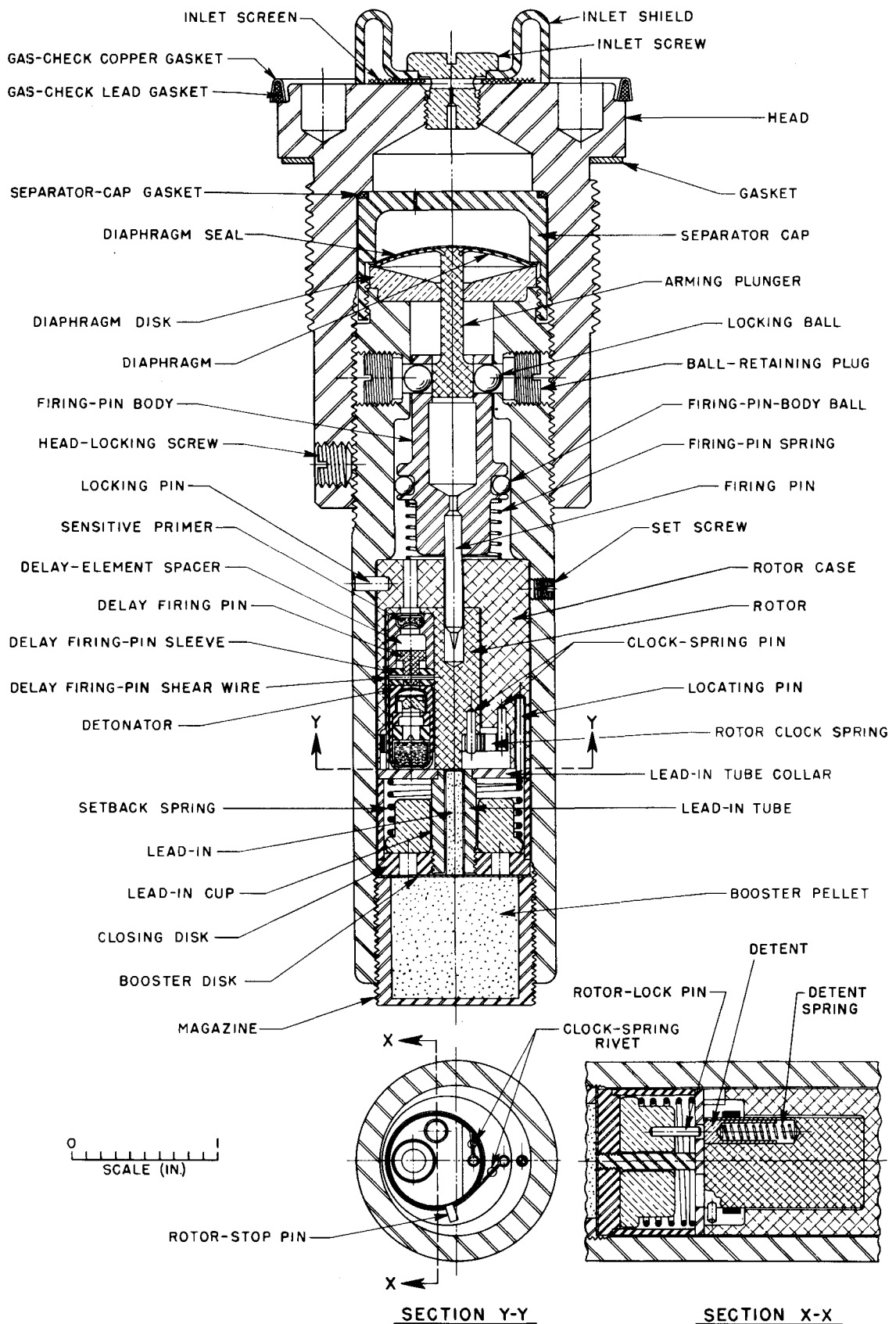


FIG. 51. PIR-9 fuze, unarmed.

3.10. PIR-9 AND PIR-14 FUZES

Rockets in which used

PIR-9: 11.75-in. Aircraft Rocket

PIR-14: 5.0-in. High-Velocity Aircraft Rocket

Dimensions and weight

Over-all length: 6.84 in.

Thread: 2.00"-12NF-2

Weight: 3.15 lb

Materials used

Body: steel

Head: steel

Diaphragm: steel

Rotor and rotor block: aluminum alloy

Explosive components

Sensitive primer: from Mk 19 fuze

Detonator (0.02-sec delay): from Mk 145 fuze

Lead-in: tetryl

Booster: from Mk 146 fuze

General arrangement drawings

PIR-9: CIT Drawing No. R3e-01

PIR-14: CIT Drawing No. R3j-01

3.101. GENERAL.—The PIR-9 fuze is a delay base fuze designed for use in the 11.75-in. AR.¹ It was intended to overcome the shortcomings inherent in the Mk 157 (PIR-2) type fuze, while retaining those features of the PIR design which had proved sound. In its operation and performance the PIR-9 is basically similar to the PIR-2, but differs from that fuze in many important details, as described below.

3.102. DESCRIPTION.—The mechanism is contained in the fuze body, which is made up of two pieces, the head and body. For strength the head and body material is pearlitic manganese steel. The head contains two gas chambers. Gas from the rocket motor is permitted to flow slowly into the first chamber through an aperture in the inlet screw after first being filtered by the inlet screen. From the first chamber the gas passes into the second chamber, formed by the separator cap and the diaphragm, through a small aperture in the separator cap. The arming plunger attached to the diaphragm holds two locking balls in such a position as to lock the firing-pin body and firing pin in a forward position, compressing a weak anticreep spring (firing-pin spring). While in the forward position, the firing pin extends through a hole in the rotor case and holds the spring-loaded rotor in an *unarmed* position so that the sensitive primer and delay detonator are out of alignment with the firing pin and lead-in. The delay-element firing pin, between the sensitive primer and delay detonator in the rotor, is fixed in a sleeve by a shear

¹ The PIR-14 is the companion fuze for use in the 5.0-in. HVAR. It differs from the PIR-9 only in having an inlet washer in place of the inlet shield and filter, and a 0.015-sec delay detonator.

wire. The lead-in is housed in an assembly containing a setback block, the function of which is to lock the rotor in the *safe* position during acceleration. The magazine, covered by a thin copper booster disk, closes the fuze body cavity.

3.103. **ARMING.**—The fuze arms in two stages:

1. Gas from the rocket motor enters the first pressure chamber through a small aperture in the inlet screw. Debris from the rocket motor is filtered out by the inlet screen. From the first chamber gas passes through the separator cap into the second chamber by another small aperture. When the pressure in the second chamber has reached a value of about 450 lb/in.², which is delayed by the small apertures until approximately one-third of the burning time is past, the diaphragm collapses, forcing the plunger down inside the firing-pin body. Movement of the plunger releases the locking balls which, in the unarmed condition, lock the firing-pin body in place, and allows the firing-pin body to move toward the rear under the force of the firing spring and inertia of the firing-pin body due to acceleration. The firing pin, attached to the firing-pin body, is withdrawn from the rotor which it normally locks in the *safe* position.

2. When the rocket accelerates, the setback block in the lead-in and rotor-lock assembly is forced back, compressing the setback spring. The rotor-lock pin, attached to the setback block, forces the detent back into its hole in the rotor and engages the rotor. When the firing pin is withdrawn from the rotor, at about one-third of the acceleration period of the rocket, the rotor, held by the rotor-lock pin, remains locked in the *safe* position. When acceleration is over the setback spring and creep force push the setback block forward, disengaging the rotor-lock pin from the rotor. The rotor spring then turns the rotor through 180°, whereupon it is stopped by the rotor-stop pin and locked by the detent. The fuze is then completely armed, with the sensitive primer and delay detonator in line with the firing pin and lead-in.

The delay of the first stage of arming, caused by the delay in admission of gas from the rocket motor to the second pressure chamber, provides safety against arming of the fuze in case a motor failure should occur shortly after ignition. Arming is not completed until the end of acceleration, after which it is accomplished in about 0.1 sec. The burning distance, and therefore the arming distance, will vary with the temperature, being approximately 300 ft and 670 ft at the upper and lower temperature limits respectively.

3.104. **FIRING.**—The fuze fires by the inertia of the firing-pin body driving the firing pin forward into the sensitive primer on impact. Detonation of the sensitive primer drives the delay-element firing pin against the percussion primer of the delay-detonator assembly. This assembly has a pyrotechnic delay of 0.02 sec, in addition to which there is added a slight delay in firing inherent in the forward motion of the firing pin on impact. The detonator initiates the following explosive sequence: (1) tetryl lead-in, (2) tetryl booster, (3) auxiliary booster of granulated TNT contained in the fuze liner, and (4) main filler of the rocket head.

3.105. **REMARKS.**—The PIR-9 fuze was developed for the purpose of correcting major weakness found to be inherent in the design of the Mk 157 Mod 1 fuze (see 3.035) and also to correct minor difficulties which had been revealed in the Mk 157 type fuze as a result of testing, manufacture, and service use. The main points in

which the PIR-9 differs from the Mk 157 Mod 1 or Mod 2 fuze may be summarized as follows:

1. **STRENGTH.**—(a) The diameter of the fuze head is reduced to a maximum of 2.36 in., and the junction between body and head is strengthened. (b) The rotor assembly is stronger than the shutter in the Mk 157 (see Item 3 below).

2. **SENSITIVITY.**—(a) The sensitivity is increased by the use of a stab-type sensitive primer; in the Mk 157 the percussion primer of the delay detonator is struck directly by the firing pin. (b) The relief of the diameter of the bore in the firing-pin body, so that the arming plunger cannot bind in the firing-pin body after arming, and the guiding of the firing-pin body by ball bearings should contribute to smoother action of the firing pin on light impacts.

3. **PERFORMANCE AT OBLIQUE IMPACT.**—The barrel rotor is not vulnerable to being knocked out of the *armed* position on heavy oblique impact as is the hinged shutter in the Mk 157.

4. **SAFETY.**—(a) The use of a plunger attached to the diaphragm eliminates the shear wire used in the Mk 157. (b) Two locking balls are specified. (c) Locking of the rotor in the *safe* position by a setback block during acceleration is more positive than the method used to lock the shutter in the Mk 157. The PIR-9 method does not permit the large gap between detonator and lead-in which is possible in the Mk 157. (d) A rubber gasket and projectile-type gas check are used to seal the fuze into the fuze adapter (as in the Mk 157 Mod 2).

5. **LOADING.**—(a) The rotor and rotor case can be finally assembled by the inert-parts manufacturer, and the rotor case held in place by a locking pin through the body wall. (b) The sensitive primer, delay-element firing pin, and delay detonator can readily be loaded into the rotor without removing the rotor from the fuze.

Only preliminary tests for safety and functioning of the PIR-9 fuze were made;¹ these did not reveal any basically unsound features in the design, but showed that the fuze was more sensitive than the Mk 157 type and at the same time capable of withstanding heavy oblique impact (2-in. STS plate at 30° in 5.0-in. HVAR with special head) without excessive damage to cause malfunction. However, the development of the PIR-9 was halted when it was decided that the PIR-19 (Mk 163) type, which was a much less radical modification of the Mk 157, offered sufficient improvement in performance over the Mk 157 and Mk 159 fuzes to satisfy the performance requirements for the rocket heads then in use.

¹ CIT/PMC 2.65, 31 December 1944, Part 2, pp. 3-5; CIT/PMC 2.66, 7 January 1945, Part 2, pp. 3-5; CIT/PMC 2.69, 28 January 1945, Part 2, pp. 10-11, p. 20.

3.11. PIR-10 FUZE

Rocket in which used

7.2-in. Demolition Rocket with Army 4.5-in. T22 Motor

General arrangement drawing

CIT Drawing No. R3h-01

3.111. GENERAL.—The PIR-10 fuze is a modification of the Mk 157 Mod 0 fuze for use in demolition rockets propelled by the Army T22 motor. It is a companion to the instantaneous fuze PIR-4, and has the same arming constants. The detonator is similar to that of the Mk 157 fuze but contains a 0.005-sec delay element.

3.112. REMARKS.—A few PIR-10 fuzes were supplied to the Army Ordnance Department for test in demolition rockets. Special detonators with 0.005-sec delay element were supplied for these fuzes by the Naval Ordnance Laboratory.

3.12. PIR-11 FUZE

Rocket in which used

Fast-burning, 100-ft-range 7.2-in. Demolition Rocket, with 2.25-in. CIT Motor Model 15 and 7.2-in. Head Mk 10

General arrangement drawing

CIT Drawing No. R3h-01

3.121. GENERAL.—The PIR-11 fuze is a modification of the Mk 146 Mod 1 (PIR-1) fuze for use in the fast-burning, 100-ft-range 7.2-in. DR, and is a companion to the PIR-8. It contains the Mk 146 Mod 1 instantaneous explosive components, and has the PIR-8 arming constants. Like the PIR-8, it has a weak anticreep spring for maximum sensitivity.

3.122. REMARKS.—A number of PIR-11 fuzes were supplied to the Army Engineer Board for test in the fast-burning, 100-ft-range 7.2-in. DR.

3.13. PIR-12 AND PIR-13 FUZES

Rockets in which used

PIR-12: 11.75-in. Aircraft Rocket

PIR-13: 5.0-in. High-Velocity Aircraft Rocket

General arrangement drawings

PIR-12: CIT Drawing No. R3f-01

PIR-13: CIT Drawing No. R3g-01

3.131. GENERAL.—The PIR-12 and PIR-13 fuzes were designed for use in the 11.75-in. AR and 5.0-in. HVAR. Like the PIR-9 and PIR-14 fuzes, they were devised in an attempt to correct the design weakness inherent in the Mk 157 and Mk 159 fuzes. They are a combination of features from the Mk 157 and PIR-9 fuzes.

3.132. DESCRIPTION.—In the PIR-12 and PIR-13 the parts associated with arming are similar to those of the Mk 157 type. The arming constants of the PIR-12 are the same as for the PIR-5 fuze, and those of the PIR-13 are the same as for the Mk 159. The over-all dimensions and threads are the same as for the Mk 157 Mod 2 and Mk 159 Mod 1 fuzes, to provide interchangeability.

The parts concerned with firing are similar to those in the PIR-9 fuze, except that no sensitive primer is used and the percussion primer of the delay detonator (0.020 sec for PIR-12 and 0.015 sec for PIR-13) is initiated directly by the firing pin.

3.133. REMARKS.—Preliminary tests of the PIR-12 fuze¹ indicated that the design was capable of withstanding heavy oblique impacts far better than the Mk 157 type. Development of the PIR-12 and PIR-13 was discontinued when the PIR-19 type of fuze was standardized to replace the Mk 157 and Mk 159.

¹ CIT/PMC 2.69, 28 January 1945, Part 2, pp. 13-14.

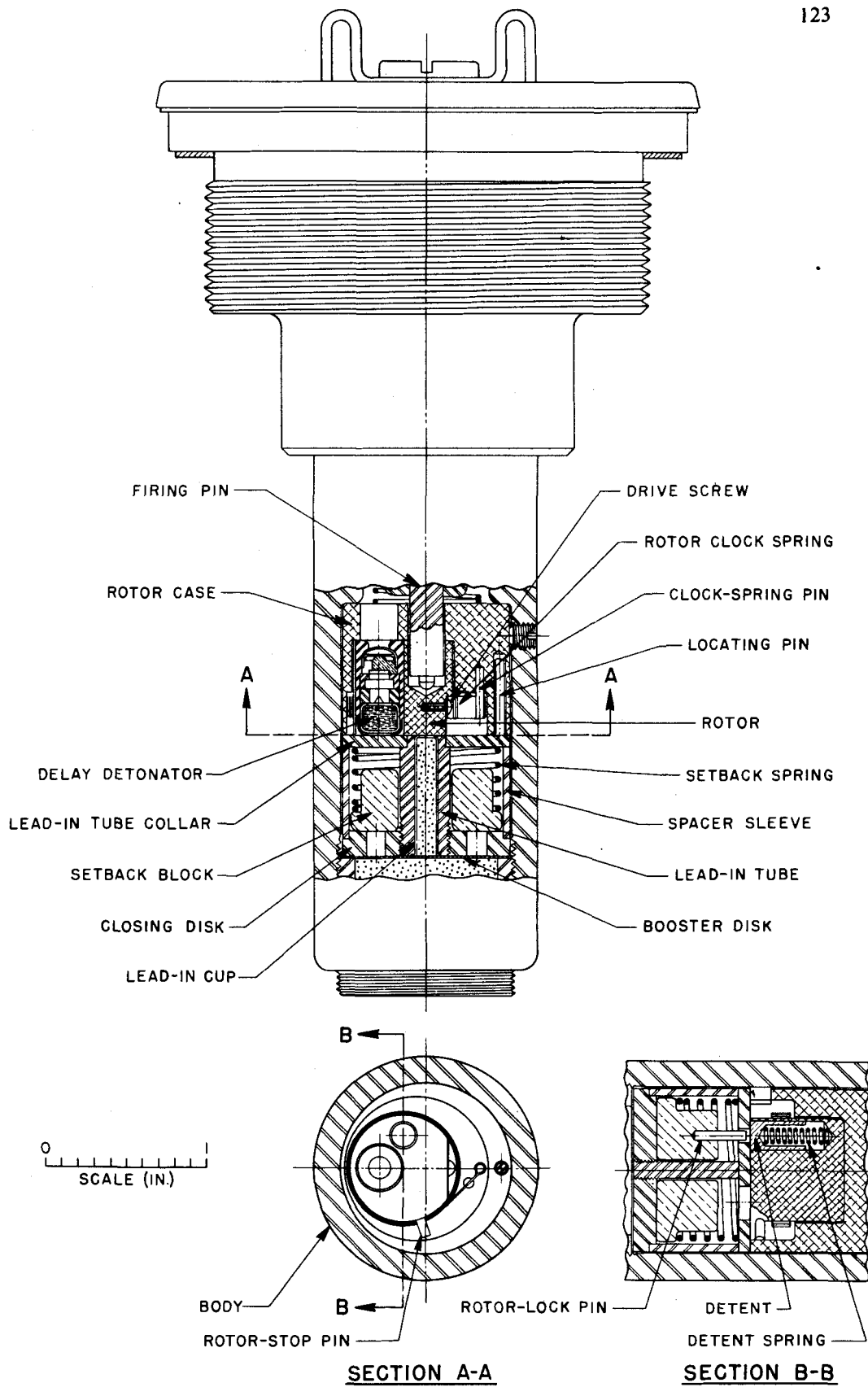


FIG. 52. PIR-12 fuze, unarmed.

3.14. PIR-15, PIR-16, PIR-17, AND PIR-18 FUZES

Rockets in which used

PIR-15 and PIR-17: 11.75-in. Aircraft Rocket

PIR-16 and PIR-18: 5.0-in. High-Velocity Aircraft Rocket

General arrangement drawings

PIR-15: CIT Drawing No. R3k-01

PIR-16: CIT Drawing No. R3l-01

PIR-17: CIT Drawing No. R3m-01

PIR-18: CIT Drawing No. R3n-01

3.141. GENERAL.—These fuzes were designed for the 11.75-in. AR and 5.0-in. HVAR for the purpose of replacing the Mk 157 and Mk 159 fuzes. They consist in slightly different combinations of features of the Mk 157 or Mk 159 fuzes with the PIR-9 type. The PIR-15 and PIR-16 are similar, as are the PIR-17 and PIR-18. Development of these fuzes did not proceed beyond the design stage owing to the adoption of the PIR-19 type of fuze.

3.15. PIR-19 (Mk 163), PIR-20 (Mk 164), AND PIR-21 (Mk 165) FUZES

Rockets in which used

Mk 163: 11.75-in. Aircraft Rocket

Mk 164: 5.0-in. High-Velocity Aircraft Rocket

Mk 165: 5.0-in. Aircraft Rocket

Dimensions and weight

	Mk 163	Mk 164	Mk 165
Over-all length:	6.49 in.	6.18 in.	6.97 in.
Thread:	2.75"-14NS-2	2.75"-14NS-2	3.625"-12NS-2
Weight:	3.2 lb	3.2 lb	5.7 lb

General arrangement drawing

Mk 163: BuOrd Drawing No. 511549

Mk 164: BuOrd Drawing No. 561460

Mk 165: BuOrd Drawing No. 561458

3.151. GENERAL.—The PIR-19 fuze was developed by modifying the Mk 157, with two principal objectives in mind:

1. To improve the performance of the PIR-type base fuzes, particularly on heavy oblique impacts, to the extent that the fuzes would function properly on the heaviest impact that the rocket heads currently in use were capable of withstanding.

2. To make the minimum modification in existing designs, in order to facilitate production changeovers.

3.152. DESCRIPTION.—The PIR-19 parts that differ from the Mk 157 parts, and their operation are shown in the enlarged sections in Fig. 53. The principal advantages afforded by this design as compared with that of the Mk 157 fuze, and a brief description of the differences follow:

1. The possible gap of 0.058 in. between the detonator and lead-in is reduced to 0.025 in., thus reducing the probability of low-order detonation of the lead-in.

2. The shutter is hinged at both ends of the hinge pin, and another detent is added. This reduces the probability of the shutter being knocked out of position by an oblique impact. The shutter spring functions only as a torsion spring and not as a compression-and-torsion spring as in fuzes of the Mk 157 type.

3. A more positive setback-operated arming delay is provided by the shutter-lock pin attached to the setback block which is housed in the lead-in and shutter-lock assembly. During acceleration of the rocket the setback spring is compressed by the inertia of the setback block, and the shutter-lock pin engages the detent hole in the shutter. When acceleration is over, the shutter-lock pin is withdrawn, releasing the shutter, which in turn is then rotated into the *armed* position by the shutter spring and locked by the two detents.

3.153. ARMING CONSTANTS.—The PIR-19 fuze, being derived from the Mk 157 Mod 2, has arming constants appropriate for use in the 11.75-in. AR, and as such was standardized as the Mk 163 Mod 0. When the inlet screen was replaced by a filter formed by compressing Inconel wire, and the inlet orifice and shear wire were replaced by those from the Mk 159 Mod 1, the fuze was designated the Mk 163

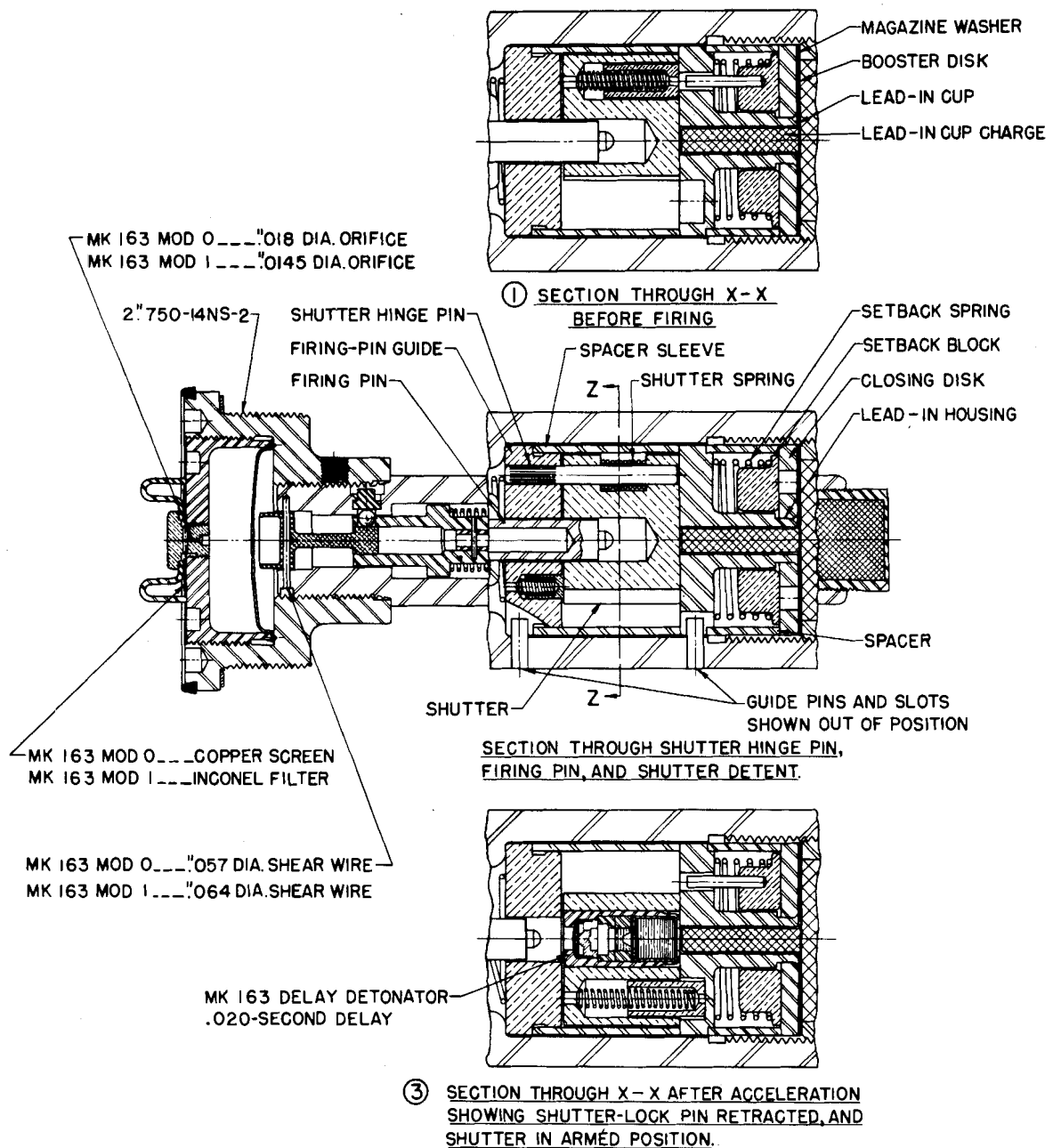


FIG. 53a. PIR-19 fuze (Base Fuze Mk 163 Mod 0 and Mod 1). The scale shown is for the enlarged sections of the drawing, which are twice the size of the unenlarged portion.

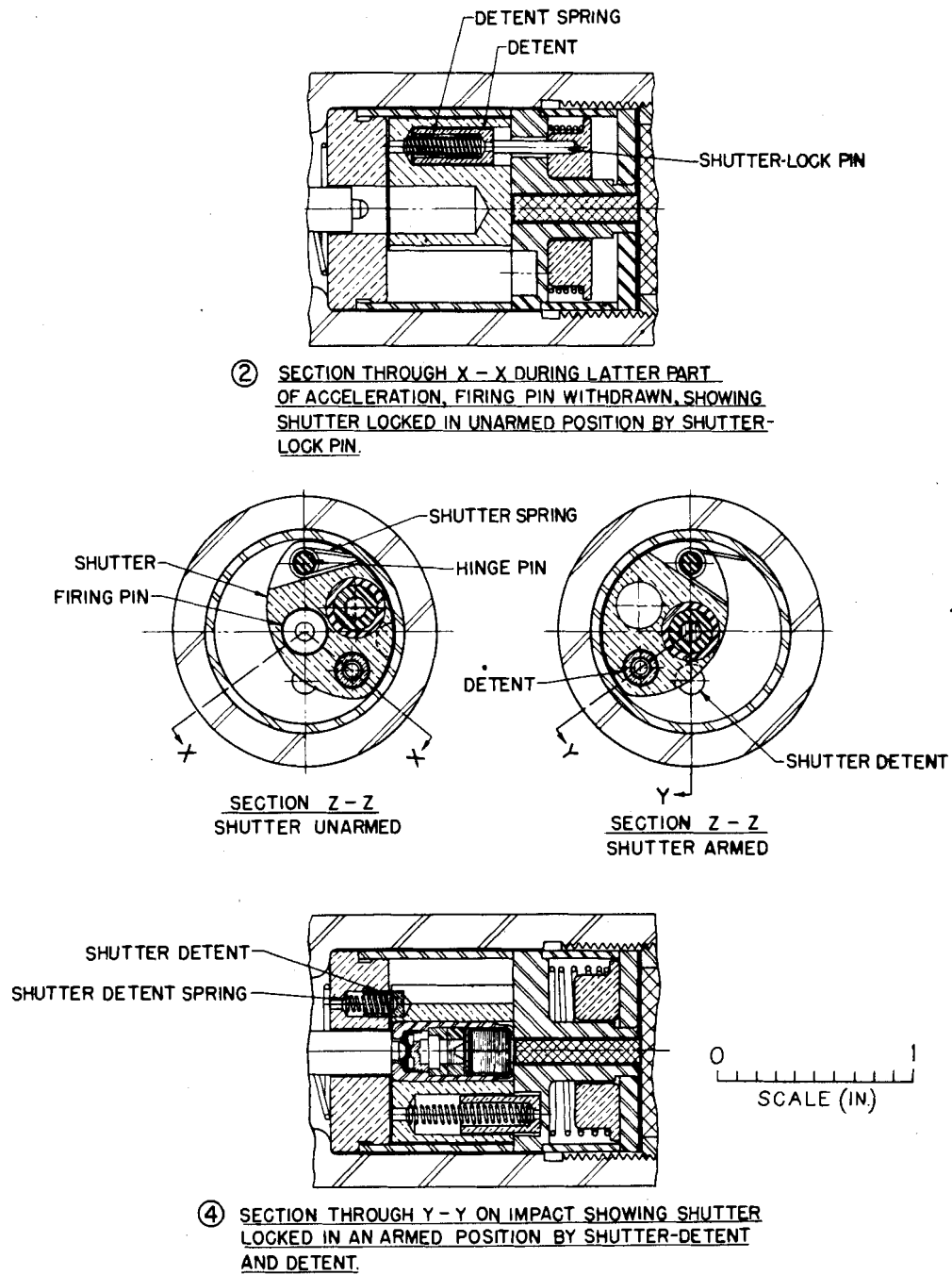


FIG. 53b. Sections through PIR-19 fuze (Base Fuze Mk 163 Mod 0 and Mod 1) shown in Fig. 53a.

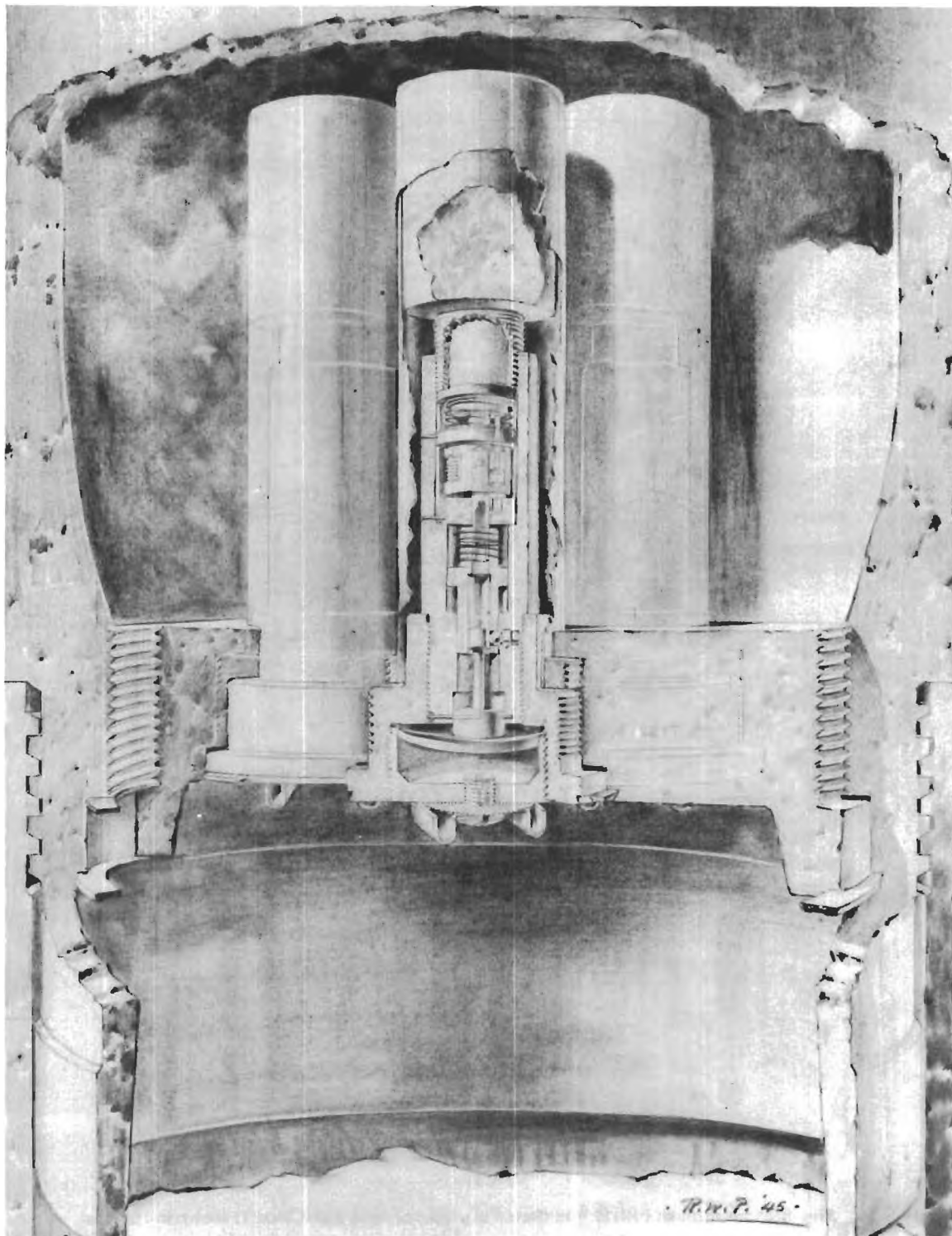


FIG. 54. Three PIR-19 fuzes (Base Fuze Mk 163 Mod 1) installed in base plug of 11.75-in. Head Mk 2 Mod 0.

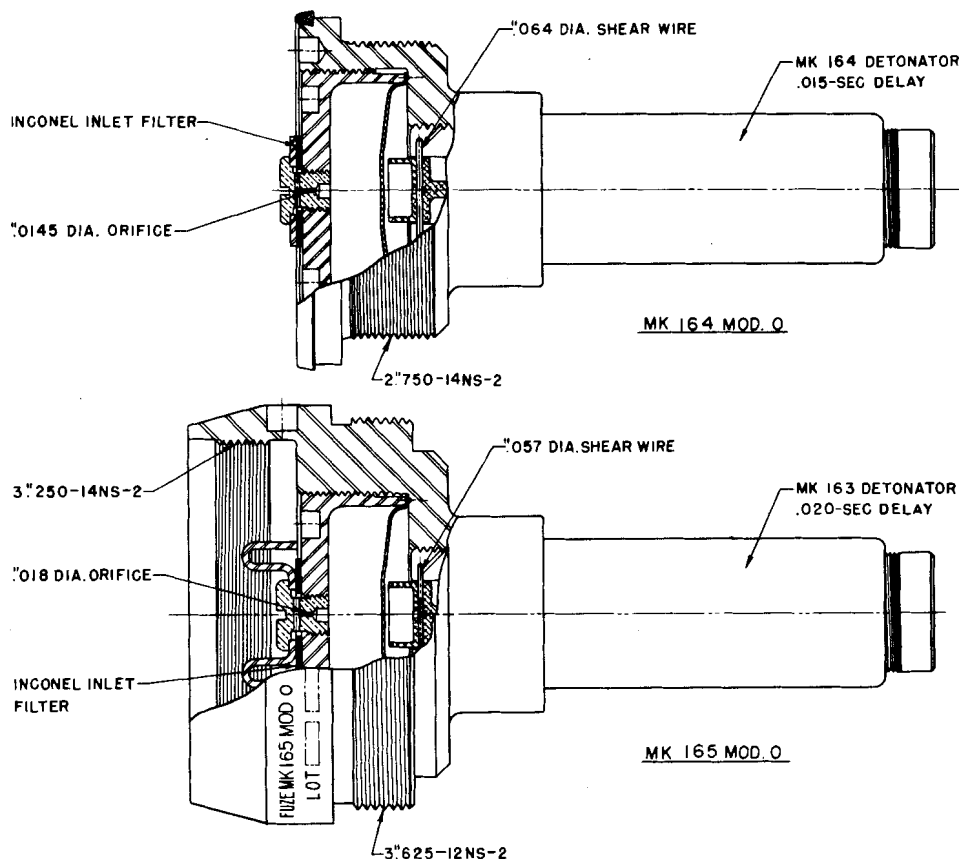


FIG. 55. Outline view of Base Fuzes Mk 164 and Mk 165 (PIR-20 and PIR-21). Except as noted or shown the fuzes are the same as shown in Figs. 53a and 53b.

Mod 1. These changes in the arming constants resulted in a higher arming pressure (350 lb/in.² instead of 290 lb/in.²) and a greater partial arming delay.

3.154. PIR-20 FUZE.—When the parts peculiar to the PIR-19, that is, those parts that distinguish it from the Mk 157 Mod 2, are used in the Mk 159 Mod 1, the resulting fuze is the PIR-20, which was standardized as the Mk 164 Mod 0. The Mk 164 also uses an Inconel filter, covered by a plain flat washer instead of the coined washer of the Mk 159.

3.155. PIR-21 FUZE.—The Mk 165 Mod 0 or PIR-21 is a modification of the Mk 160 Mod 0 fuze¹ made by the substitution in this fuze of the parts peculiar to the PIR-19. The Mk 160 Mod 0 fuze, which was never produced for service use, was identical with the Mk 157 Mod 0 fuze except that in the Mk 160 (and Mk 165) the fuze head and rocket motor adapter are made in one piece.

3.156. REMARKS.—The over-all length of the Mk 163, 164, and 165 fuzes is

¹ See PIR-2 fuze, Section 3.03.

approximately 0.33 in. greater than that of the Mk 157 Mod 2, 159 Mod 1, and 160 Mod 0 fuzes respectively. The additional length, which appears in the extension of the magazine from the fuze body, requires a deeper fuze cavity in the fillers of the 5.0-in. Mk 1 and Mk 6 heads. In the 11.75-in. Mk 2 head the fuze seat liner is not changed to accept the Mk 163 fuze, but the length of the auxiliary booster is changed.

A series of tests were performed¹ to evaluate the performance of the PIR-19 fuze in 5.0-in. Mk 1 and 5.0-in. Mk 6 heads against plate and to test new detonator designs devised by the Naval Ordnance Laboratory. These indicated that the PIR-19 type of fuze offered a definite improvement over the Mk 157 type, but that satisfactory performance in heads stronger than the 5.0-in. Mk 1 and Mk 6 could not be expected.

During the period March to June, 1945, approximately 20,000 Mk 163 Mod 0 and 50,000 Mk 165 Mod 0 fuzes were manufactured and loaded by CIT by assembling Mk 146, Mk 157 Mod 2, Mk 157 Mod 0, and Mk 160 fuze parts obtained from Navy contractors with new PIR-19 type parts.

¹ Reported in the following numbers of CIT/PMC: 2.70, 4 February 1945, Part 2, pp. 11-13; 2.71, 11 February 1945, Part 2, pp. 4-7; 2.73, 25 February 1945, Part 2, pp. 2-5; 2.74, 4 March 1945, Part 2, pp. 8-11; 2.79, 15 April 1945, Part 2, pp. 3-8; 2.80, 29 April 1945, Part 2, pp. 3-6; 2.82, 27 May 1945, Part 2, pp. 1-4; 2.84, 24 June 1945, Part 2, pp. 6-7. See also CIT/OIC 12.1, 20 September 1945.

3.16. PIR-22 AND PIR-23 FUZES

Rockets in which used

PIR-22: 5.0-in. High-Velocity Aircraft Rocket, with 5.0-in. Motor Mk 1 and 5.0-in. Head Mk 2

PIR-23: 11.75-in. Aircraft Rocket

Dimensions and weight

Over-all length: 6.02 in.

Thread: 2.125"-12NS

Weight: 2.0 lb

General arrangement drawings

PIR-22: CIT Drawing No. R4A-01

PIR-23: CIT Drawing No. R5A-01

3.161. GENERAL.—The PIR-22 fuze is a pressure-arming, impact-firing, fixed-delay base fuze.¹ It is designed for use in rocket heads such as the common type 5.0-in. Mk 2 head. This head is capable of withstanding far more severe impacts than the 5.0-in. Mk 6,² and earlier tests had shown that the Mk 164 (PIR-20) fuze was incapable of reliable functioning, even at the limiting conditions for heads stronger than the 5.0-in. Mk 6.

The PIR-22 fuze contains many features of the Mk 166 (DDR-4), but because it is of the impact-firing type, the mechanism involved in firing is simpler than that in the Mk 166 fuze. The principal weaknesses of the Mk 164 fuze which the PIR-22 was designed to overcome are stated below.

1. The large diameter fuze head of the Mk 164 necessitates a narrow and relatively weak base plug in the 5.0-in. Mk 2 head; as a result the base plug and fuze are easily torn out of the head on heavy oblique impact. In addition the body of the Mk 164 may break off at the junction with the fuze head at such impact.

2. The shutter mechanism of the Mk 164, while strong enough to stand up under most impacts that the 5.0-in. Mk 6 head is capable of withstanding, is not strong enough to be suitable for use in the 5.0-in. Mk 2 head.

3. The sensitivity of the Mks 163, 164, and 165 leaves much to be desired. In the PIR-22 a stab-type sensitive primer and a heavy firing-pin weight, which could be mounted on ball bearings if necessary, were expected to yield improved sensitivity.

4. The delay-detonator assembly of the type used in the Mks 145 and 157, although very convenient because of being a single unit small in size, is not considered entirely satisfactory for various reasons (see 2.09). The PIR-22 uses the delay assembly from the projectile base fuzes (Mks 19, 20, 21, etc.), which have been more than adequately tested in AP projectiles.

3.162. DESCRIPTION.—From the rear end of the fuze forward through the rotor the PIR-22 fuze is identical with the Mk 166 (DDR-4), and the arming constants

¹ The PIR-23 fuze is identical with the PIR-22 in all respects except the arming constants, which are the same as those of the Mk 162 (DDR-3).

² About 3.0 in. of STS plate for the 5.0-in. Mk 2 head as compared with about $\frac{3}{4}$ in. of STS plate for the 5.0-in. Mk 6 head.

are the same. The firing-pin weight is keyed to the rotor in the same fashion as the trigger block in the Mk 166. This weight has two notches in its forward end so that it is free to slide forward (against the anticreep spring) around the stop pins in the body after it has been rotated 90° from the *safe* position by the rotor in arming. The firing pin is crimped in place inside one end of the weight. Two pins key the detonator case to the weight so that both the weight and detonator case are rotated by the rotor in arming. The detonator case is constrained by the flange on its forward end from moving axially with respect to the fuze body. The detonator case may contain either the Mk 20 fuze type of pyrotechnic train with a 0.010-sec delay element or the instantaneous type of train from the Mk 28 fuze. The detonator and lead-outs are the same as are used in the Mk 166 fuze. Tetryl lead-ins are provided in the body 90° from the *unarmed* position of the tetryl lead-outs in the detonator case. The lead-ins connect with the booster charge in the magazine at the end of the fuze body in the same manner as in the Mk 166 fuze.

3.163. **ARMING.**—After completion of the pressure phase of arming, which is identical with that of the Mk 166 fuze (5.012), the rotor turns the firing-pin weight and detonator case through 90°, lining up the slots in the weight with the stop pins in the body, and the lead-outs in the detonator case with the lead-ins in the body. Detents in the body then engage grooves in the outside of the weight and thus hold the weight in alignment with the stop pins, and the lead-outs with the lead-ins.

3.164. **FIRING.**—The fuze is fired on impact when the inertia of the weight compresses the anticreep spring and the firing pin is driven into the sensitive primer, initiating the explosive train.

3.165. **REMARKS.**—Preliminary tests¹ gave the following indications concerning the PIR-22 fuze:

1. The fuze is capable of functioning properly in the 5.0-in. HVAR with the 5.0-in. Mk 2 head at impact on plate near the limit for this head (3.0-in. STS at 0° obliquity and 2.0-in. STS at 40° obliquity, at 1800 ft/sec striking velocity).
2. It is capable of consistent functioning on mild steel plate down to $\frac{3}{8}$ in. or less in thickness, at 1800 ft/sec striking velocity in the 5.0-in. HVAR.
3. It is detonator-safe in the *unarmed* position.

¹ CIT/PMC 2.89, 15 September 1945, Part 2, pp. 2-3; CIT/OIC 12.1, 17 September 1945.

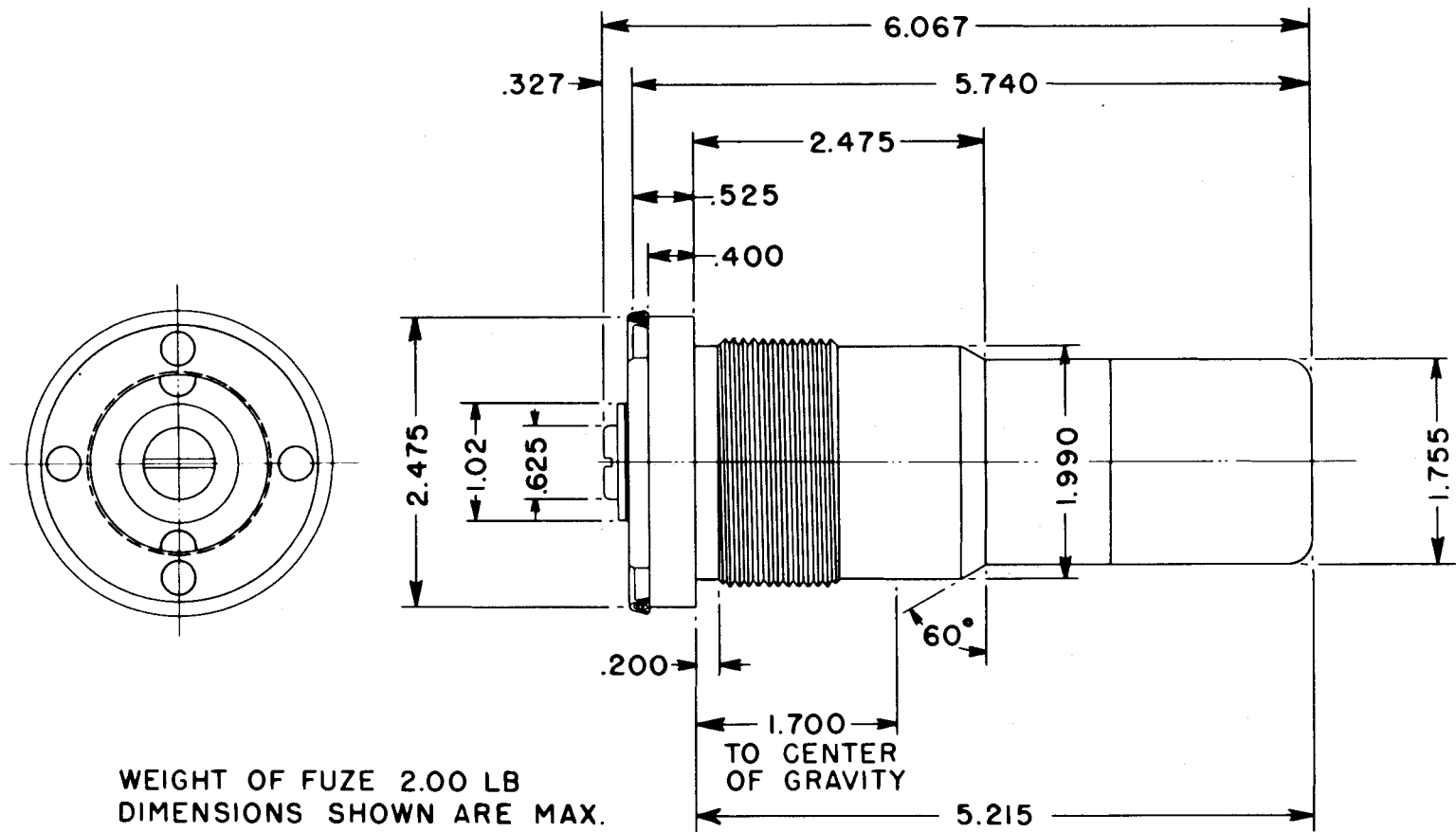


FIG. 56. Outline view of PIR-22 fuze.

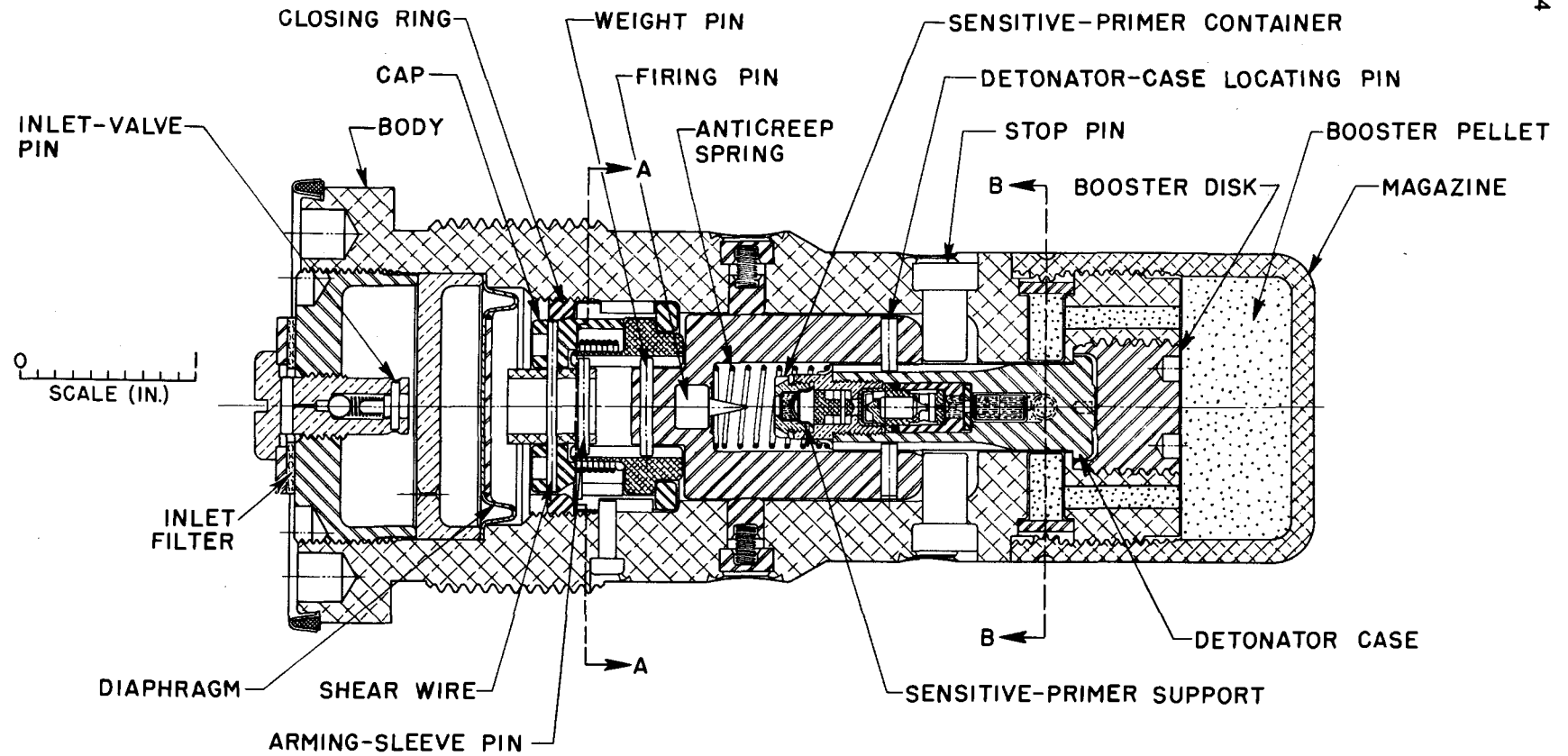


FIG. 57. PIR-22 fuze, unarmed.

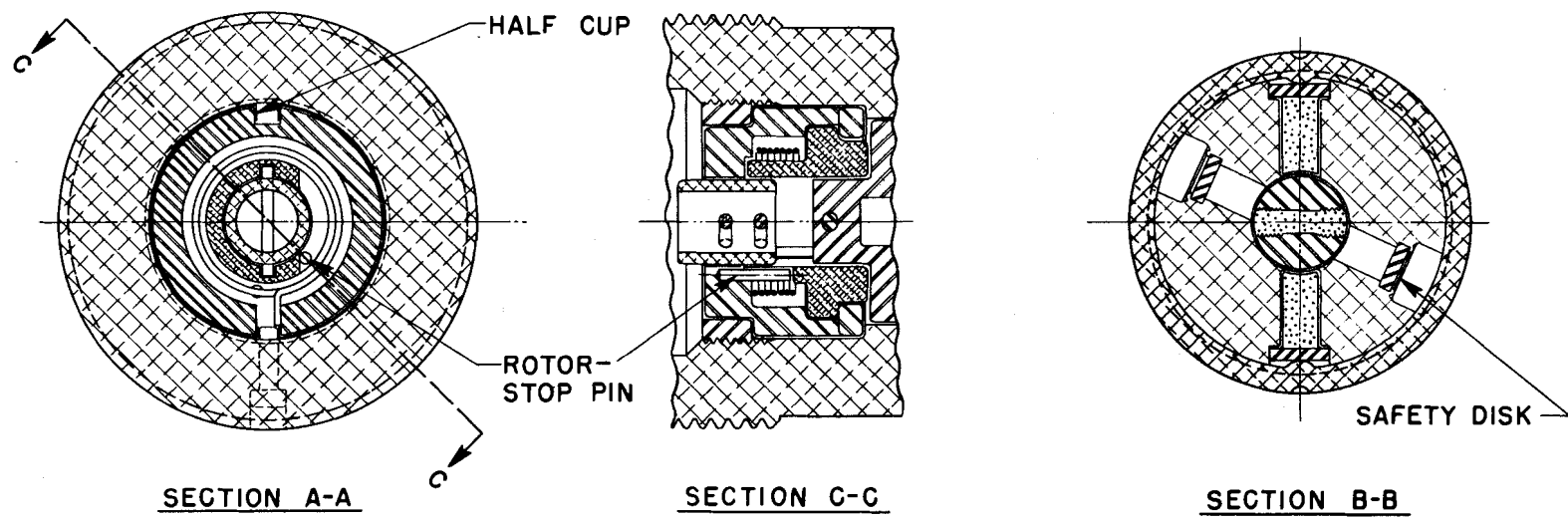


FIG. 58. Sectional views of unarmed PIR-22 fuze shown in Fig. 57.

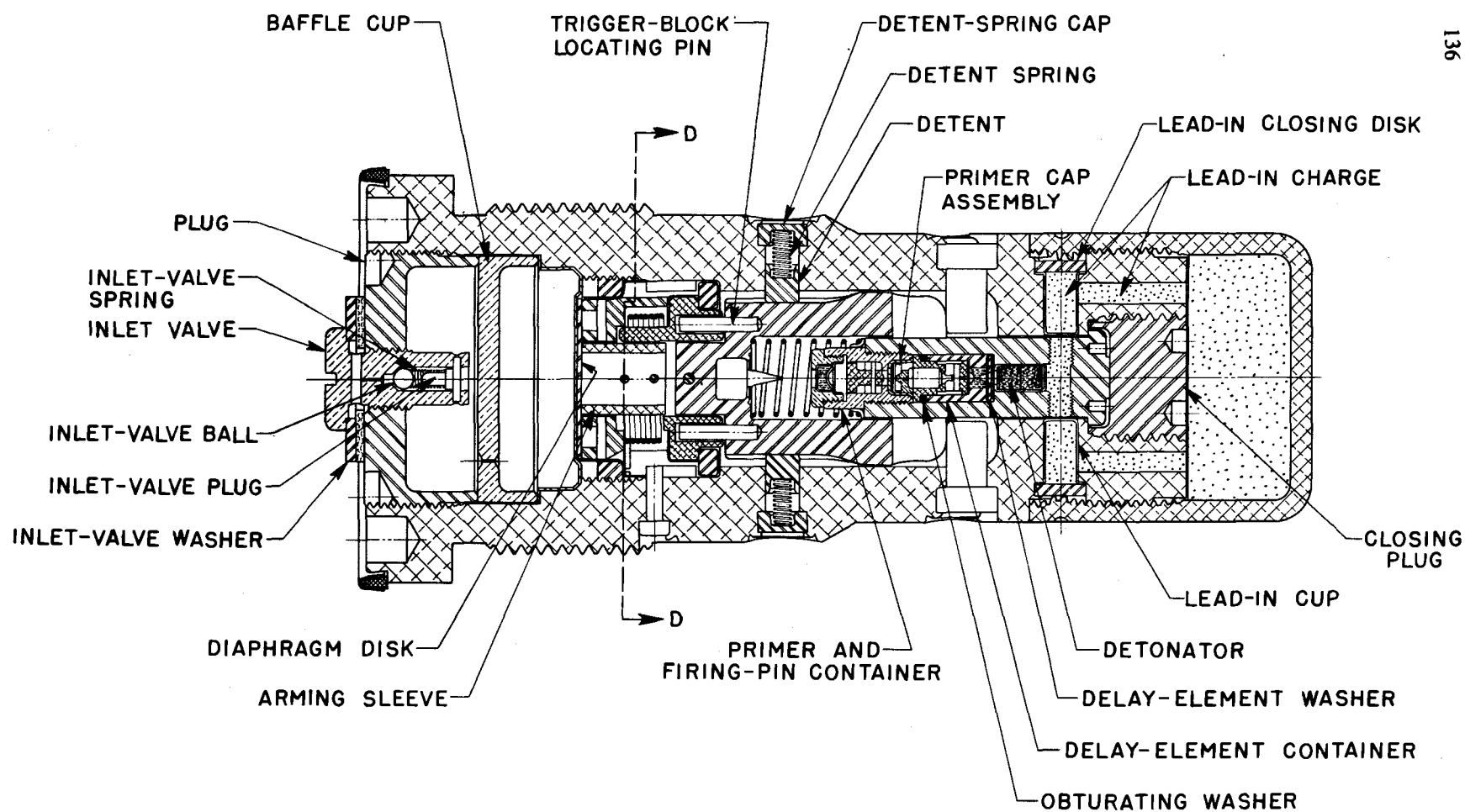


FIG. 59. PIR-22 fuze, armed.

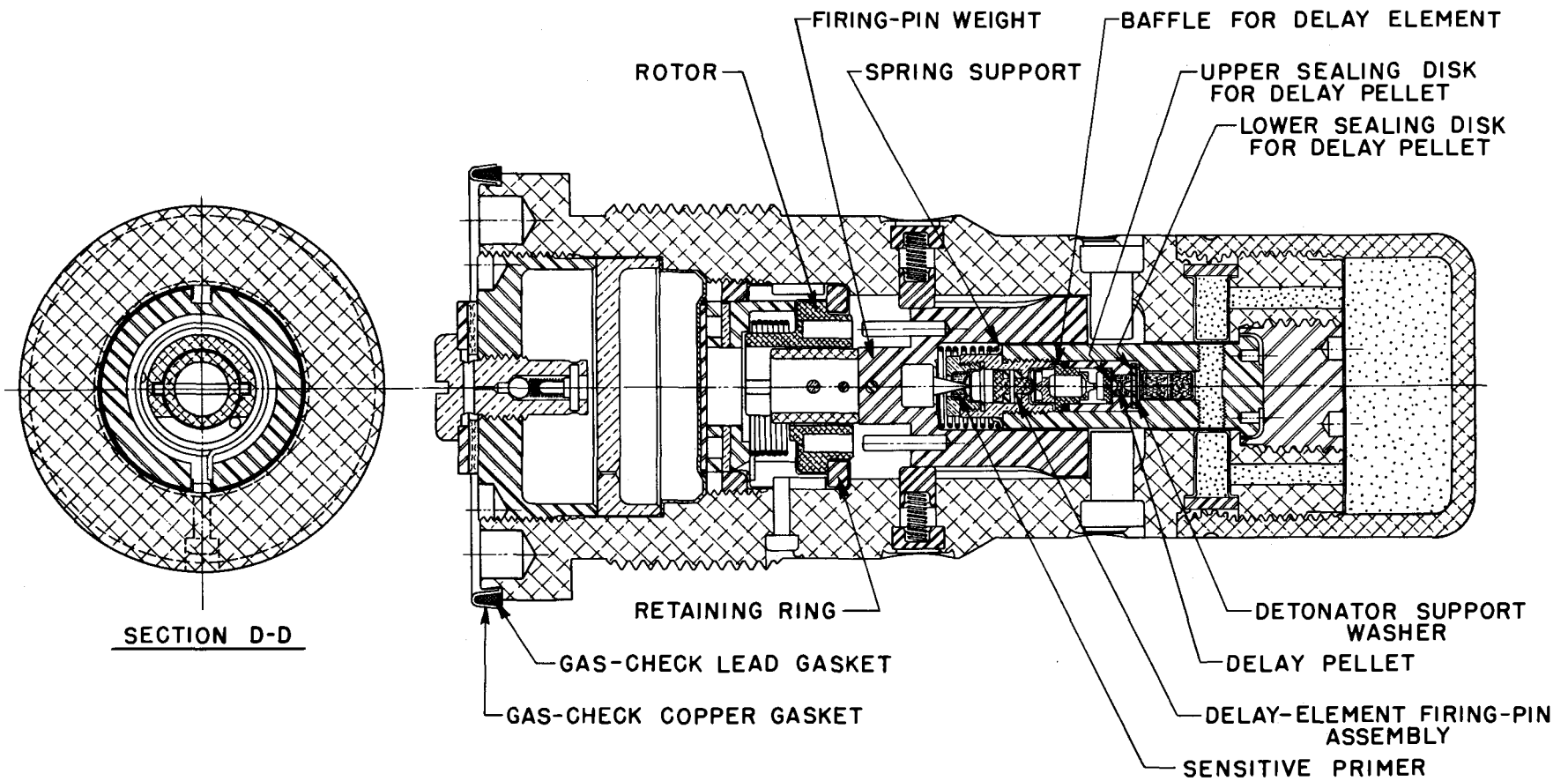


FIG. 60. PIR-22 fuze, fired, and Section D-D of Fig. 59.

Chapter 4

NIR FUZE

4.00. INTRODUCTION.—The NIR (nose-pressure-arming, impact-firing, rocket) fuze is a point-detonating nose fuze intended for the high-velocity aircraft rockets. It is armed by the aerodynamic pressure built up at the nose of the projectile. After some development work had been done it became apparent that because of the low value of this pressure at velocity below that of sound (see 4.02), the fuze could probably not be used successfully on the 5.0-in. AR; work on this fuze was therefore dropped, and the AIR-8 fuze was developed to fill the requirement.

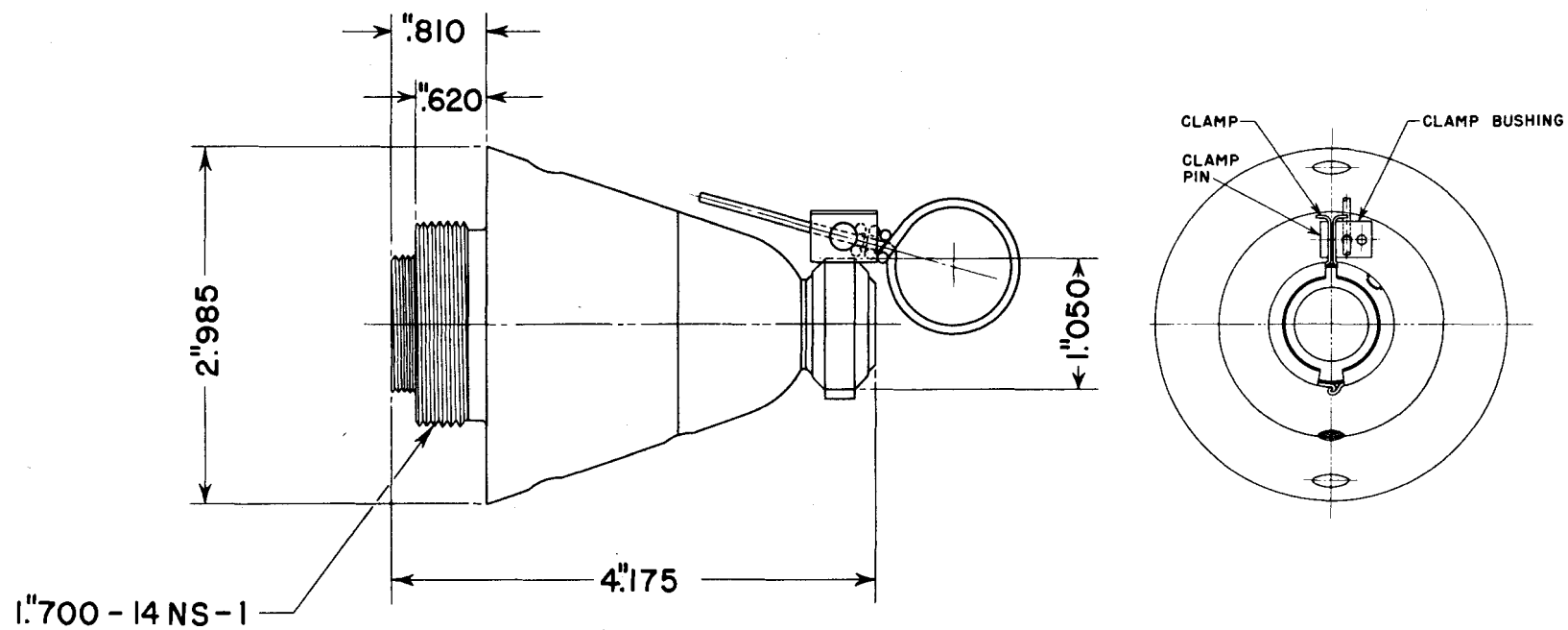
There are, however, certain rockets in which the NIR fuze could be used to distinct advantage. The following may be mentioned:

1. The AIRCRAFT ROCKETS, when the air speed of the launching aircraft is greater than about 300 knots. At higher air speeds the AIR-8 fuze is partially armed only a few feet from the aircraft; that is, the firing pin is completely screwed out and the shutter restrained only by the setback lock.¹ It is quite possible that under these conditions the AIR-8 fuze would become armed if a motor blowup should occur within the first few feet of rocket travel. Since the forward velocity of the head would then be small, there would be some chance of the head striking the aircraft. If this happens, it is quite desirable to have the fuze still in the *safe* condition. Although the partial arming distance of the AIR-8 fuze may be increased by increasing the pitch and inertia of the propeller (as was done with the AIR-7 fuze), no great increase is possible, nor is the partial arming distance of the resulting fuze likely to be very uniform. The partial arming distance of the NIR fuze, on the other hand, may be increased without resultant nonuniformities, the maximum attainable arming distance depending on the minimum rocket and aircraft velocity at which the fuze is expected to operate.

2. SLOW-SPIN FIN-STABILIZED ROCKETS.—The British have done some work with a high-velocity rocket that is essentially fin-stabilized but has a spin of a few hundred rev/min imparted by the launcher. This spin presumably effects a reduction in the dispersion caused by jet and mechanical malalignments. The spin is great enough to prevent the proper functioning of a propeller-arming fuze, but it is not sufficient to allow a fuze to be armed by centrifugal force. With appropriate modifications in the shutter design to compensate for centrifugal force, the NIR fuze could easily be adapted to such a rocket.

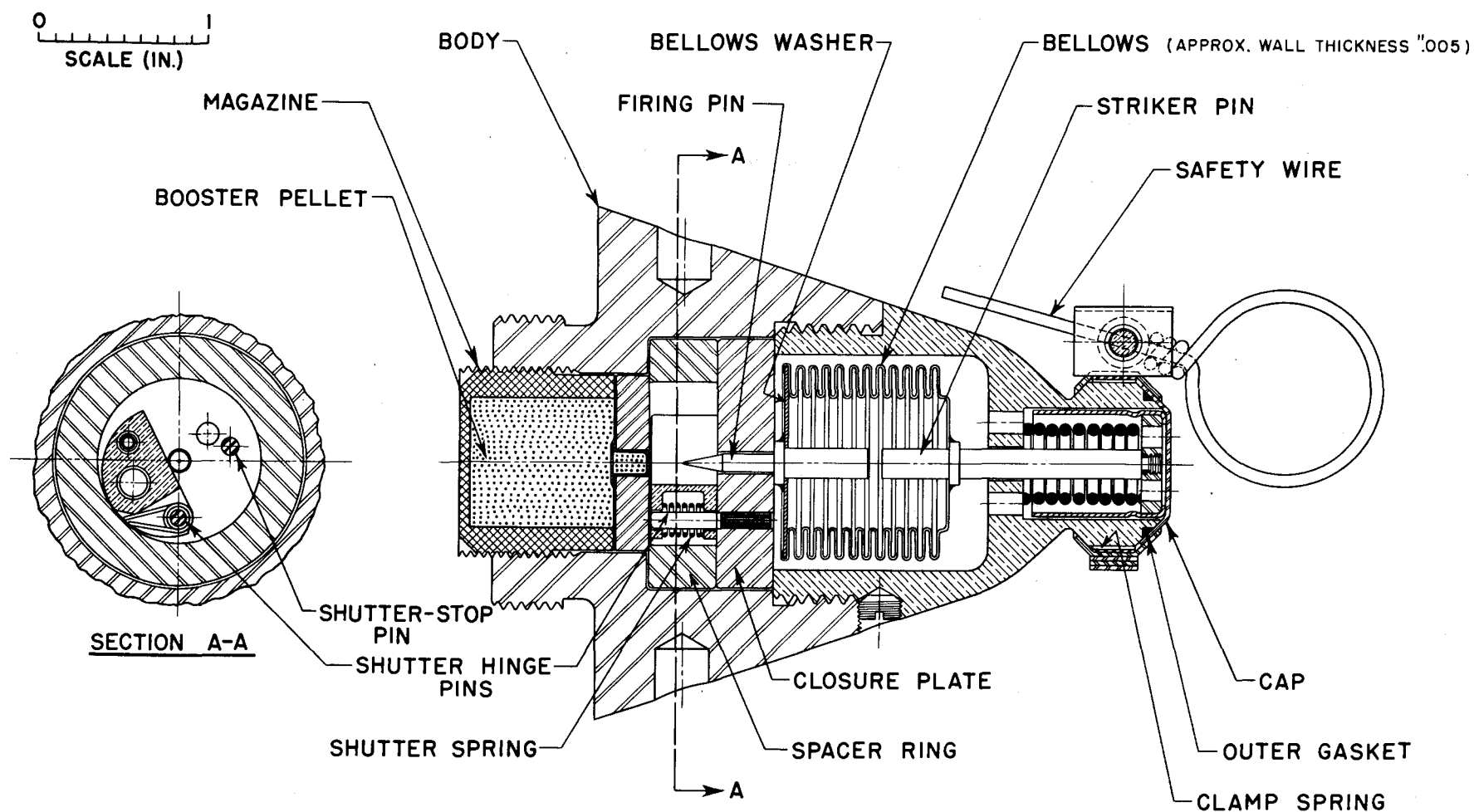
3. PRESPUN SPIN-STABILIZED ROCKETS.—It has been suggested that for various applications the spinner rockets be given the required rotation entirely in and by the launcher. There are several important objections to such a scheme, among them the difficulty of fuze design. A fuze for such a rocket could not be safely armed by centrifugal force, nor could it be armed by setback, since rocket setback is much less than the frictional forces resulting from centrifugal force, which would be great because of the high spin velocity and the fact that the axis of rotation of

¹ See PMC 2.34, 28 May 1944, Part 2, p. 18.



(ALL DIMENSIONS ARE MAXIMUM)

FIG. 61. Outline view of NIR-2 fuze (Nose Fuze Mk 144).



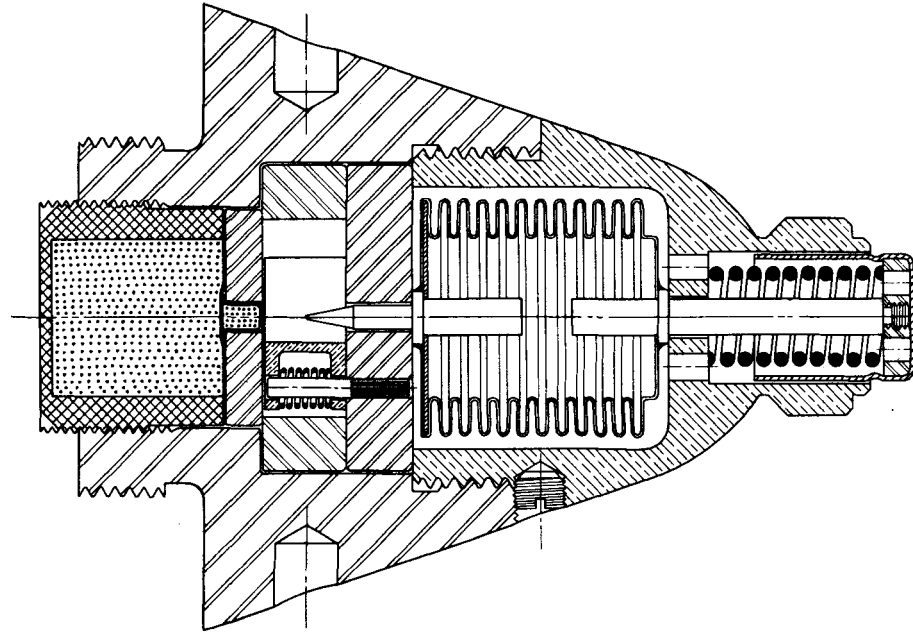
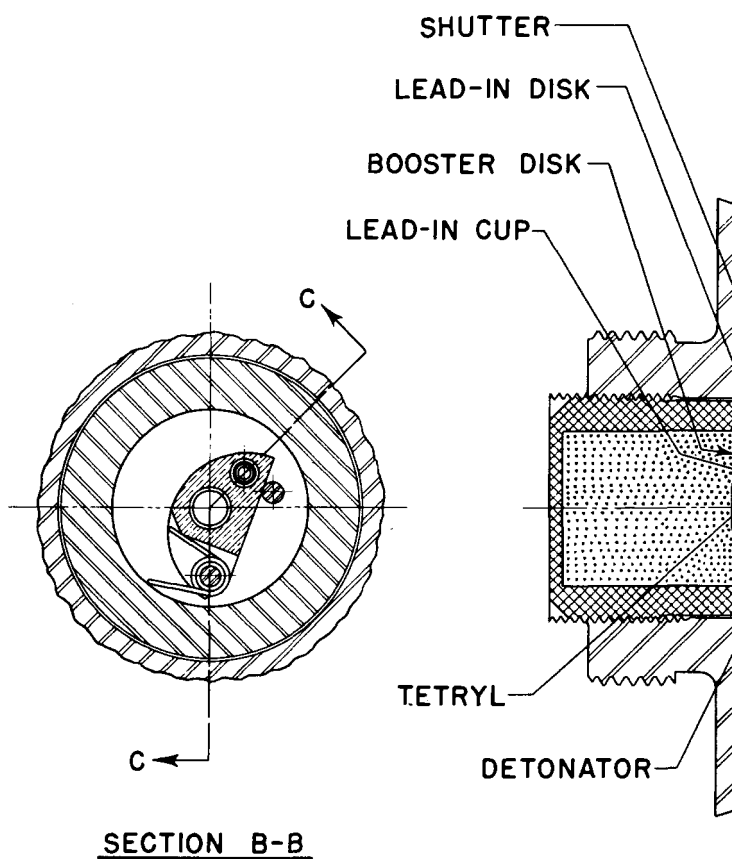


FIG. 63. NIR-2 fuze, showing position of parts during burning of rocket motor.



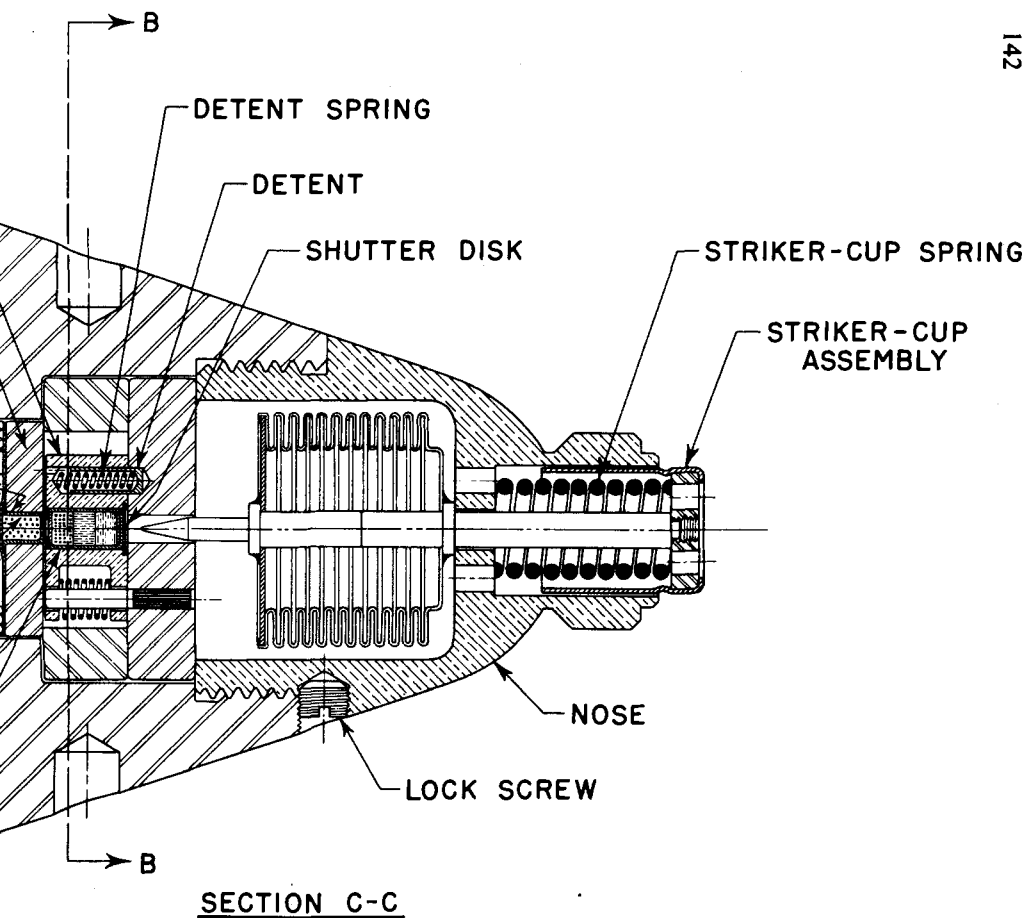


FIG. 64. NIR-2 fuze, armed.

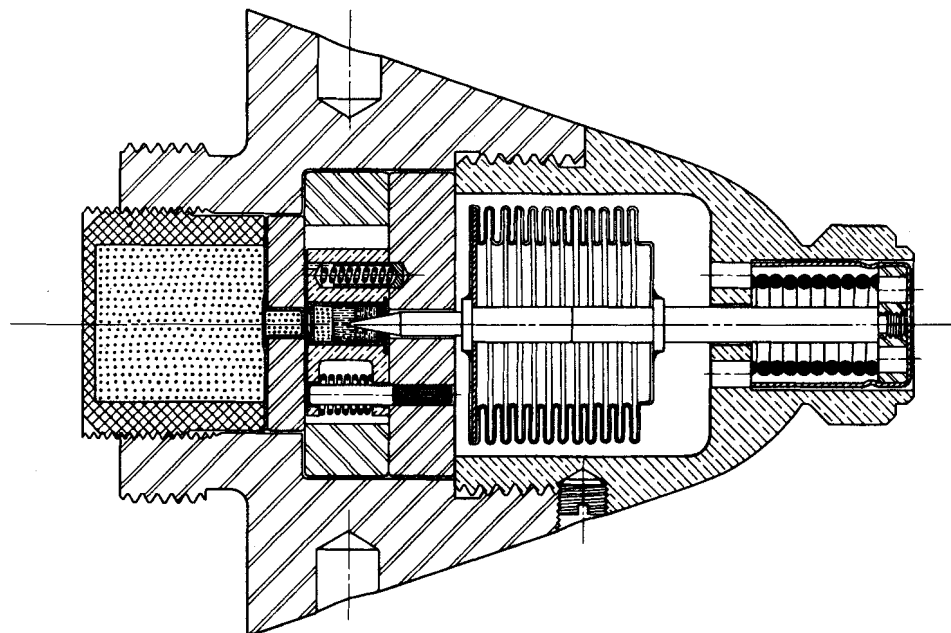


FIG. 65. NIR-2 fuze, fired.

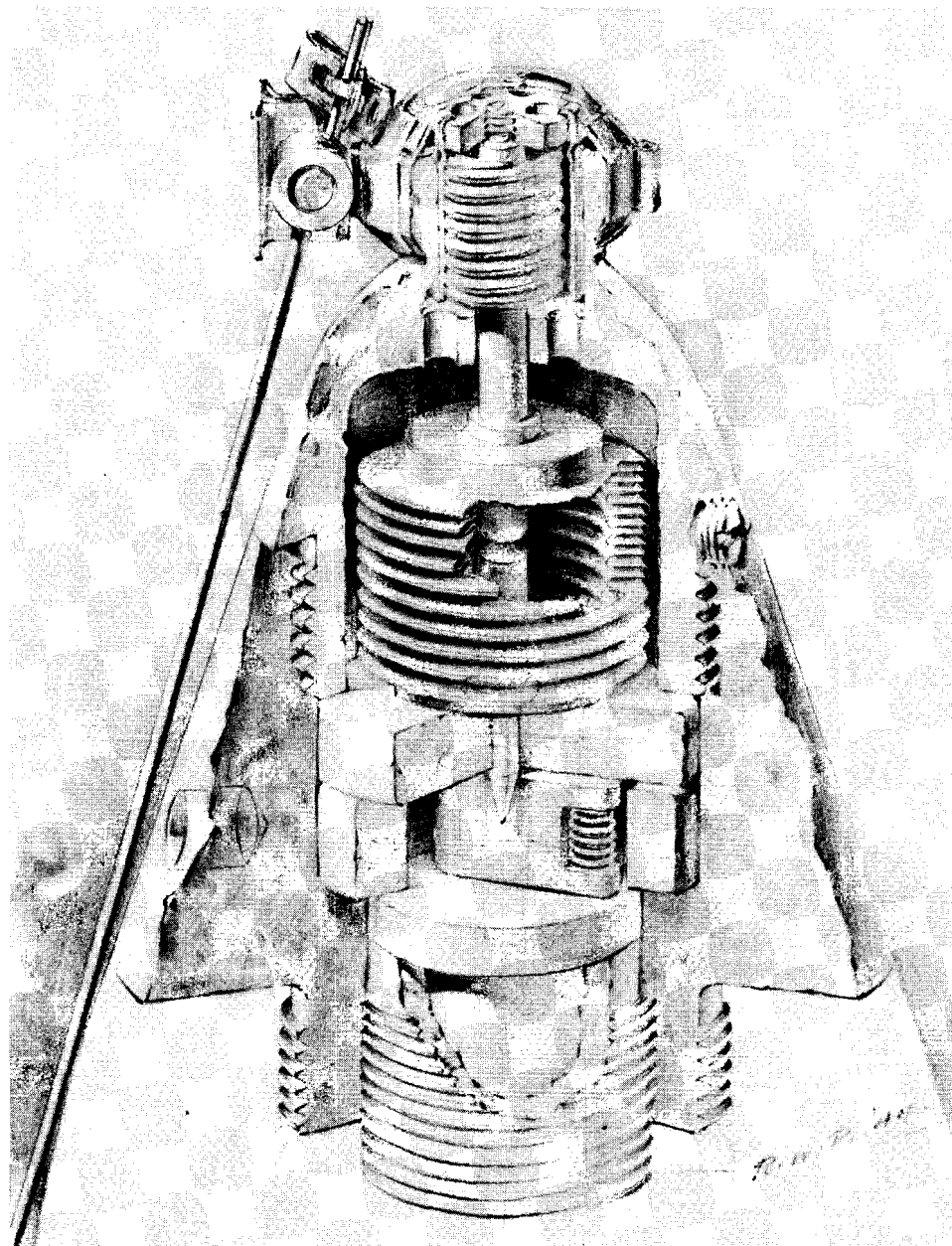


FIG. 66. NIR-2 fuze, unarmed (Nose Fuze Mk 144).

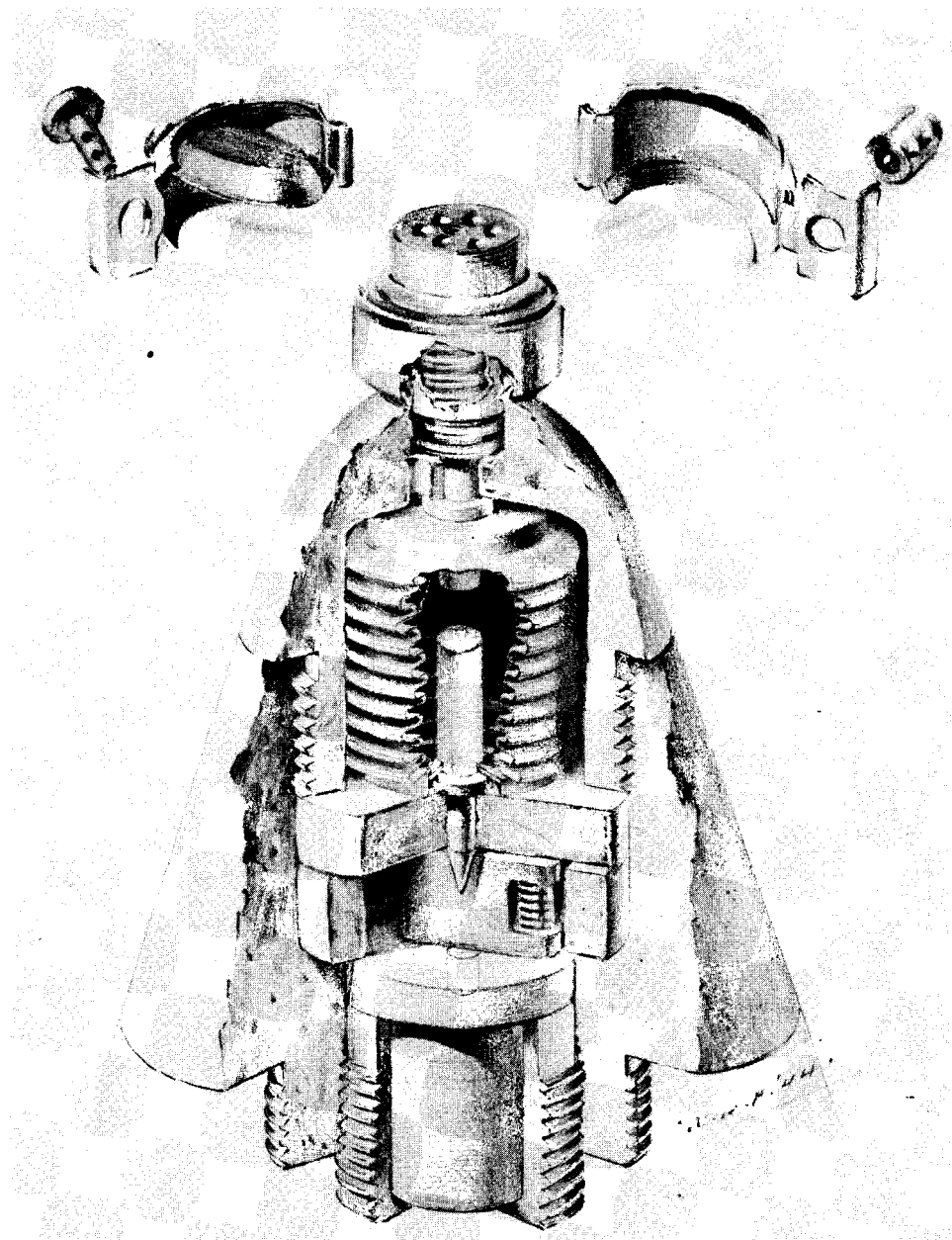


FIG. 67. NIR-2 fuze (Nose Fuze Mk 144), immediately after rocket is launched.

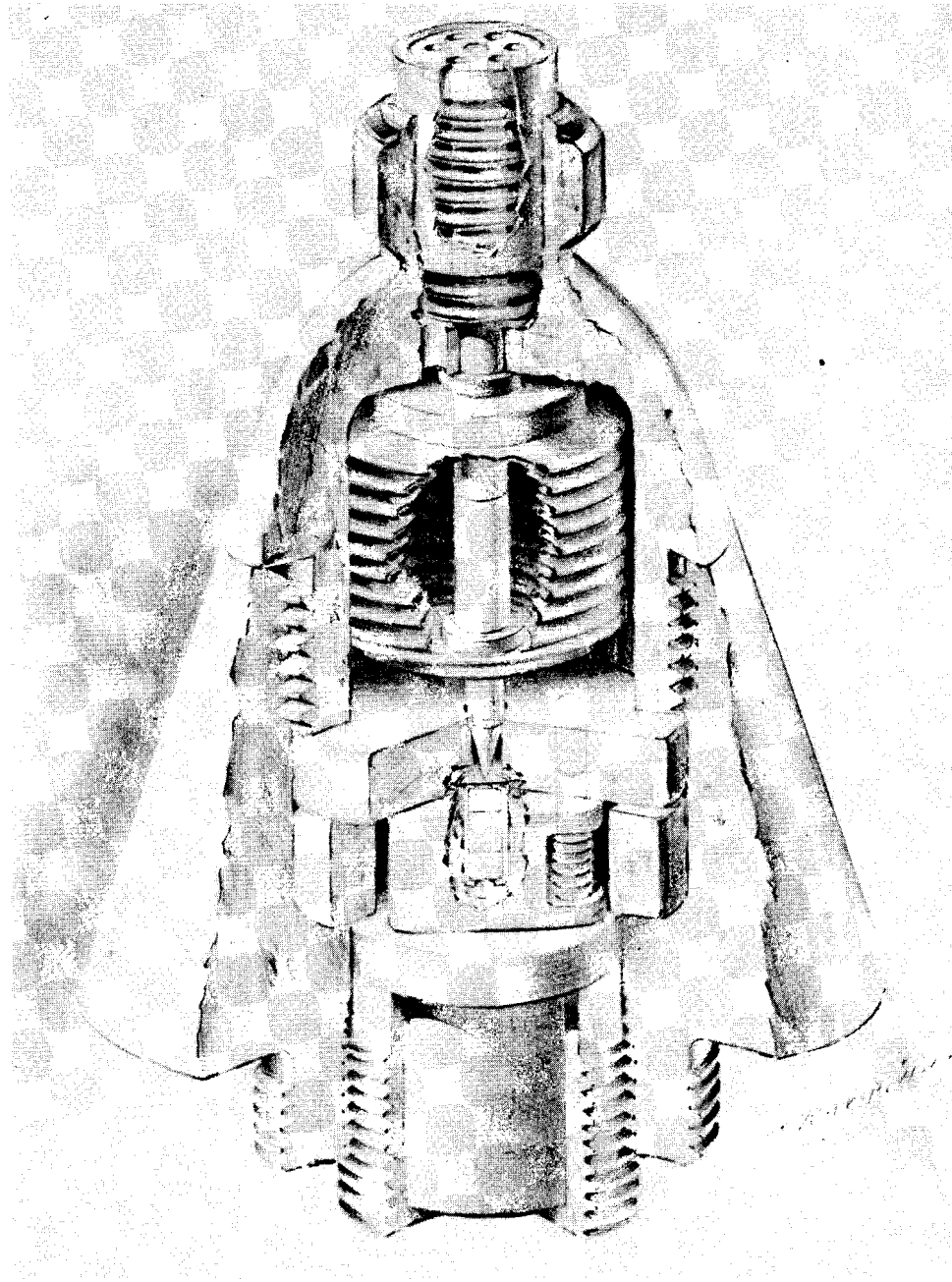


FIG. 68. NIR-2 fuze, armed (Nose Fuze Mk 144).

the rocket seldom coincides with the geometrical axis of the fuze. However, if the burnt velocity were high enough and considerable care were taken to keep all moving parts light, the NIR type of arming could probably be used for a nose fuze.

4. ANTISUBMARINE FUZE.—With appropriate modifications the NIR fuze would have certain advantages over the Mk 140, Mk 156, and Mk 158 fuzes as an antisubmarine fuze (see 4.03).

4.01. GENERAL REQUIREMENTS AND DESCRIPTION OF NIR-2 FUZE.—The requirements for the NIR-2 fuze¹ are the same as for the AIR-7 and AIR-8 fuzes (2.07 and 2.08), and need not be repeated here. The NIR-2 and AIR-8 fuzes may be used in the same rockets, and they contain the same explosive components.

The fuze action may be described briefly. The fuze is weather-proofed by a cap and clamp similar to those of the AIR-8. An arming wire is inserted through the clamp bushing when an assembled round is loaded on an airplane, and one end of the arming wire is attached to a standard bomb arming-wire release on the airplane. Thus the arming wire may either be released with the round so that the nose fuze remains unarmed, or kept with the aircraft so that the fuze can become armed, as the pilot may desire.

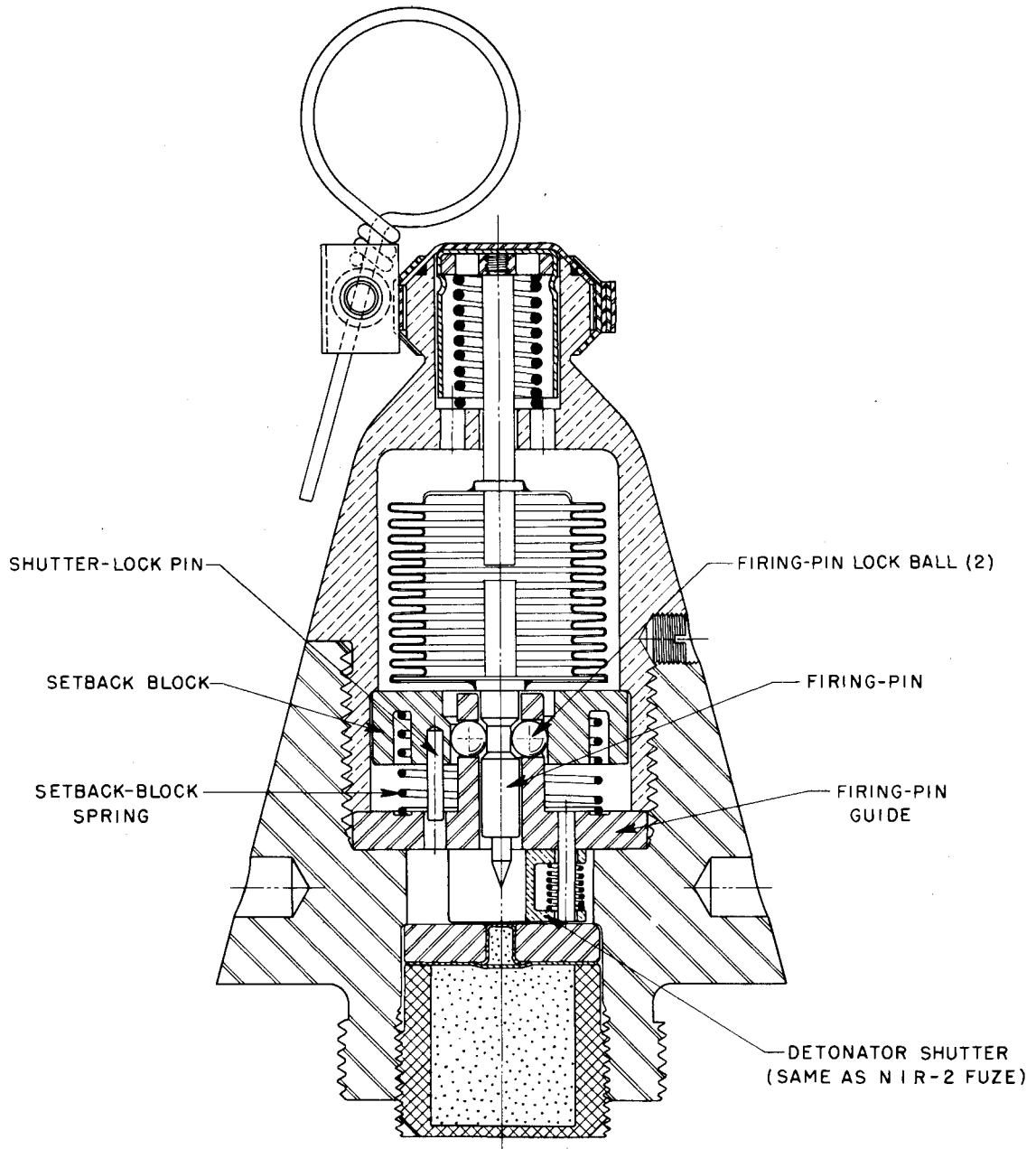
When the arming wire is kept with the aircraft at rocket firing, it is pulled out of the bushing, releasing the clamp and allowing the cap to fly off. The striker is moved forward by the striker spring, and the bellows² expands longitudinally to fill the entire cavity in the fuze, leaving the firing pin in its original position. As the rocket gains speed aerodynamic pressure builds up in front of the striker, and air flows back into the fuze and around the bellows. As this pressure increases, the bellows, being sealed, collapses and withdraws the firing pin from the detonator-shutter cavity. At a pressure determined mainly by the stiffness of the bellows, the firing pin is withdrawn far enough to free the detonator shutter, which is similar to that in the AIR-8 fuze. In general, setback forces will prevent the shutter from moving until the end of burning of the rocket motor, at which time the shutter moves to the *armed* position. In this position the detonator is lined up with both the firing pin and the lead-in.

During flight the rocket gradually loses speed because of air drag, and the pressure on the nose of the fuze drops correspondingly. If the range is great enough the bellows may expand sufficiently to allow the firing pin to press against the detonator. To prevent the detonator from being pierced an 0.008-in.-thick protective sheet of brass or aluminum is crimped in the shutter over the detonator. On impact the striker and firing pin are forced back, initiating the detonator, the explosive train of the fuze, and the main high-explosive filler.

The protection over the detonator has not been shown to be necessary; indeed, the rocket would certainly have to lose a great deal of its speed before the firing pin would press hard enough to pierce even the unprotected detonator. On the other hand, a rocket motor failure near the end of burning would result in very

¹ Only the fuze for aircraft rockets, development of which was actually started, will be considered in this and the following section. This fuze was designated the Nose Fuze Mk 144 by the Navy.

² A commercial corrugated brass bellows, of the type manufactured by the Fulton Sylphon Company.



PARTS NOT NAMED
CORRESPOND TO NIR-2 PARTS

0 1
SCALE (IN.)

FIG. 69. NIR-1 fuze, unarmed.

erratic flight of the rocket and possibly in sudden removal of the nose pressure as the rocket tumbles. Under these conditions the firing pin might easily pierce an unprotected detonator with enough force and velocity to initiate it, and thus the head.

A setback feature may be easily added to the fuze, as shown in Fig. 69. As is apparent from the illustration, this modification results in a fuze that cannot be armed except by the simultaneous application of setback and pressure and that does not complete arming until after setback ceases at the end of burning of the rocket motor. This feature seems to be desirable; it is certain that without it the fuze in a rocket installed on an airplane could become armed without the round actually being fired. This could be caused by an improperly assembled arming wire, which might come out of the bushing and free the cap and clamp. The air speed of the aircraft, added to the blast of an adjacent rocket, could then arm the fuze.

Preliminary tests have indicated that the NIR fuze should perform quite satisfactorily and reliably. It should fire on water and earth at very high obliquities and in general be more sensitive than the AIR-8. The theoretical relation between the arming pressure and the air speed at which the fuze arms (see 4.02) has been roughly verified, and the setback mechanism of the NIR-2 has been tested sufficiently to indicate that it would probably be satisfactory.

4.02. THEORY; GENERAL DISCUSSION OF OPERATION.—The following equations are given by aerodynamic theory:

$$\frac{P_n}{P_a} = \left[1 + \frac{\gamma - 1}{2} \left(\frac{V}{V_s} \right)^2 \right]^{\frac{\gamma}{\gamma - 1}} \quad \left(\frac{V}{V_s} \leq 1 \right) \quad (1)$$

$$\frac{P_n}{P_a} = \frac{\left[\frac{\gamma + 1}{2} \left(\frac{V}{V_s} \right)^2 \right]^{\frac{1}{\gamma - 1}}}{\frac{2\gamma}{\gamma + 1} \left(\frac{V}{V_s} \right)^2 - \frac{\gamma - 1}{\gamma + 1}} \quad \left(\frac{V}{V_s} \geq 1 \right) \quad (2)$$

These equations give P_n , the pressure on an essentially large flat surface (of the order of 0.5 in. in diameter) moving with a velocity V , as a function of P_a , the atmospheric pressure, V_s , the velocity of sound at atmospheric temperature, and γ , the ratio c_p/c_v of specific heats for air. These functions are plotted in Fig. 70. Note that P_n is the total pressure.

The arming pressure of the NIR fuze is determined by the characteristics of the bellows assembly used. By selecting bellows from the various types available commercially one can get a wide variety of arming pressures. The manufacture, assembly, and sealing of the bellows offer several problems, which presumably have been solved by the manufacturers.¹ The pressure and temperature of the air inside the bellows when it is sealed have an influence on the arming pressure, of

¹ The bellows assembly would undoubtedly be the most expensive component of the fuze.

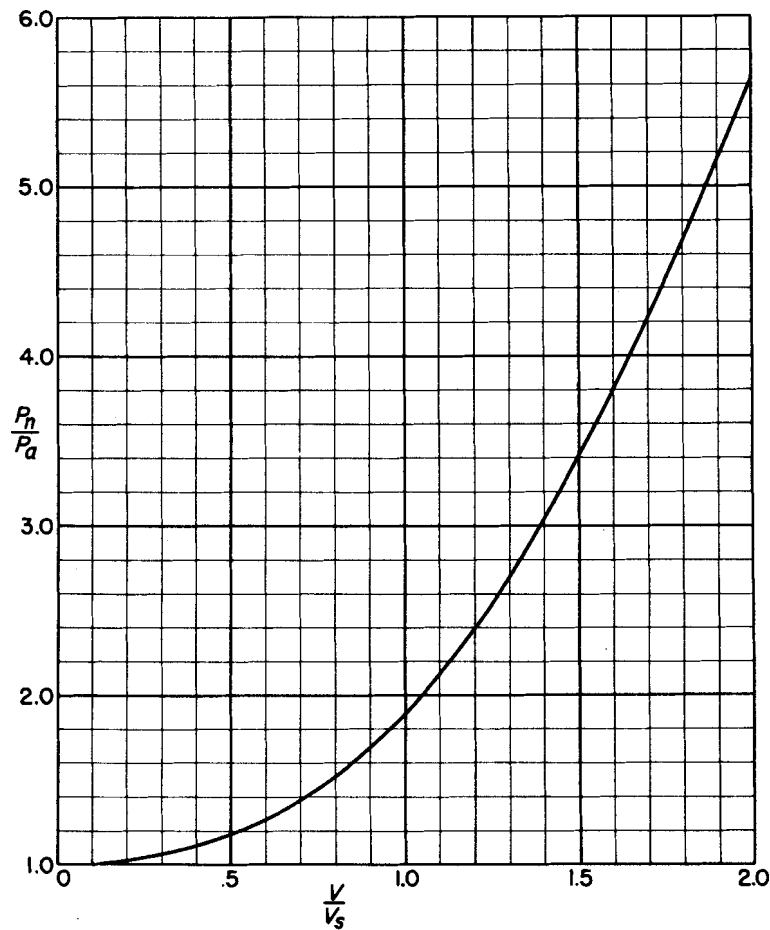


FIG. 70. Ratio of pressure on a flat surface to atmospheric pressure vs. ratio of velocity of the surface to velocity of sound.

course. It might be possible to retain a low vacuum inside the bellows and thus avoid variations of arming pressure with temperature, but this seems hardly practical, since it must be possible to store the fuzes for periods of several years. A slow leak communicating with the inside of the bellows would compensate for this temperature variation, but the leak would have to be so slow, corresponding to a very long and very small hole (of the order of 0.001 or 0.002 in. in diameter by 0.5 in. to 1 in. long), that it too would probably be impractical. If then the bellows is sealed at atmospheric pressure P_0 , an absolute temperature T_0 ($t^\circ\text{F} + 460^\circ$), and a length corresponding to the collapsed bellows (as in either the completely *safe* or completely *armed* fuze), then the internal pressure in the bellows will vary inversely with the absolute temperature. If P_e is the total external pressure required to overcome the mechanical springiness of the bellows, and T_i

is the internal temperature of the bellows at the time the fuze is fired, then the total arming pressure, P_A , is given by

$$P_A = P_s + P_0 \frac{T_i}{T_0} \quad (3)$$

If T_0 is 590° absolute (130°F), P_0 is 14.7 lb/in.², and T_i varies from 0°F to 130°F, then the contribution of the second term on the right to the arming pressure will vary from 11.5 to 14.7 lb/in.² Variations in T_0 , the temperature at which the bellows is sealed, may be of the same order of magnitude as this.

It is apparent from consideration of these possible temperature variations, as well as the possible variations in atmospheric pressure and P_s (from the necessary manufacturing tolerances), that one must avoid specifying too small an arming pressure. It was required originally that the fuze, when assembled in a 5.0-in. AR having a burnt velocity of 720 ft/sec, should arm when fired at air speeds as low as 200 ft/sec, corresponding to level flight of slow, patrol-type aircraft. The resultant total velocity of 920 ft/sec corresponds to an arming pressure of 23.5 lb/in.², which is only 8.8 lb/in.² greater than standard atmospheric pressure of 14.7 lb/in.². This was the reason for substituting the AIR-8 fuze for the NIR and for stopping work on the latter. In general, an attempt to use the NIR fuze should not be made unless the conditions of use are such that the resultant total velocity of the rocket will always be greater than the speed of sound (1090 ft/sec), in which case $P_A - P_a = 13.2$ lb/in.²

4.03. THE NIR AS AN ANTISUBMARINE FUZE.—It has been suggested that the NIR fuze might be modified for use as a contact antisubmarine fuze to replace the Nose Fuzes Mk 140, Mk 156, and Mk 158 in such weapons as the 7.2-in. ASR and projector-charge ammunition (Hedgehog) for shipboard use, and small contact bombs dropped from aircraft, the fuze being armed by hydrostatic pressure. The more apparent advantages and disadvantages of the fuze as modified for anti-submarine use are stated below. The general requirements for the antisubmarine fuzes are given and discussed in Ch. 7.

Some of the possible advantages are:

1. The fuze could be fairly completely weather-proofed. It is true that extended storage will cause the flexible fiber gasket used under the cap to dry out and shrink, thereby losing some of its effectiveness;¹ also, exposure of the cap and clamp to highly corrosive atmospheres must be prevented by coating these parts with light vaseline or other grease; still, the fuze is not nearly so vulnerable to exposure as the Mk 140 and other impact-firing fuzes for ASR, and the existence of a detrimental amount of corrosion is more easily determined. In addition, a fairly large amount of icing of the fuze before firing should not interfere with its proper functioning, and icing of a cold fuze in the water may not cause difficulty (see Ch. 7).

2. Prematuring (firing of the fuze coincidentally with arming) on water entry

¹ The gasket is the same type used in the AIR-8 and SIR fuzes. When a fuze with such a dried gasket is placed in water, a drop or two of water may be allowed to enter before the gasket swells sufficiently to become effective again.

would be impossible, since the force on the striker of the fuze is greatest at the instant of water impact, before any hydrostatic pressure can have built up around the bellows. If the striker is forced back by this initial force the fuze cannot arm, regardless of the pressure around the bellows, until the striker returns to the forward position under the influence of the striker spring. It should thus be possible to adjust the various constants of this fuze so that it would arm consistently at a quite shallow depth over a wide range of entry velocity.

3. The NIR fuze should be much less subject to countermining¹ than the inertia-firing fuzes mentioned above; however, as far as is known, countermining has not caused any great trouble in service use of those fuzes.

Some possible disadvantages and difficulties that might be encountered in adapting the NIR for use as an antisubmarine fuze should be mentioned.

1. The manner of firing of the fuze is such that a part of the fuze itself must come into contact with the target. The minimum angle of incidence at which the fuze will function is thus determined by the shape of the complete projectile. Any alteration of the nose shape of the rocket in an attempt to make the striker of the fuze function at low incidence angles will change the underwater behavior of the projectile, probably for the worse rather than better, increasing the dispersion and the underwater drag.

2. Once the peak force of water impact is past (see Item 2 above), the striker spring must be strong enough to move the striker forward against hydrodynamic forces which depend on the projectile velocity and the striker shape and size. However, the strength of this spring is limited by the mechanical strength of the cap-and-clamp assembly, which must restrain the striker in the completely unarmed fuze, and by the maximum "softness" of target on which it is desired to have the fuze function.

3. The bellows might have to be supported internally against excessive pressure.

¹ The sympathetic detonation, under water, of one round by another.

Chapter 5

DDR FUZE

5.00. INTRODUCTION.—The DDR (deceleration-discriminating rocket) fuze is intended for use in those aircraft rockets that have a useful underwater trajectory, as a substitute for the AIR-9, 10, and 11 fuzes. It is a pressure-arming base fuze rather than a nose fuze, and satisfies the basic requirement for these fuzes through an entirely different principle of operation. This basic requirement, as well as some of the more important facts concerning the underwater trajectories of these aircraft rockets, has been mentioned in 2.09. One obvious characteristic of these rockets may be mentioned, that they travel under water nose-first and with their longitudinal axis essentially parallel to the direction of motion. The deceleration caused by water drag is then always in the direction of this axis, and it is this deceleration that is utilized in the DDR fuze.

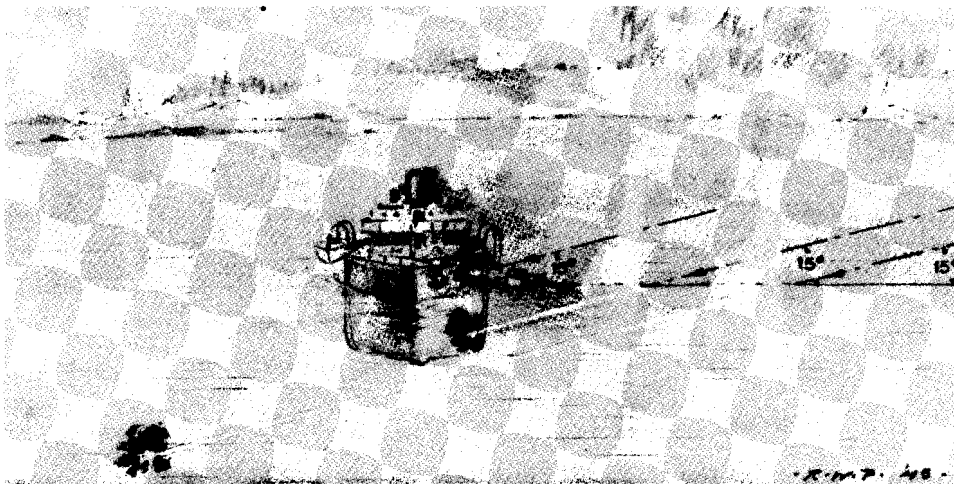


FIG. 71. Underwater action of DDR-3A fuze (Base Fuze Mk 162 Mod 0) in 11.75-in. Aircraft Rocket on (a) hitting and (b) missing target.

The operation of the fuze may be described briefly as follows: The initial impact serves to unlock a trigger mechanism, which is controlled by the underwater deceleration. As long as the deceleration remains above a certain value, nothing happens. However, when the deceleration drops below this value, either because the rocket is slowing down or because it has penetrated into a ship and is traveling through air (a less resistant medium), then the trigger releases a spring-activated firing pin, initiating the explosive train of the fuze and the high explosive in the rocket head. Thus the fuze satisfies the basic requirement of a fuze for the underwater aircraft rockets, since it will detonate the head within a ship after a hit

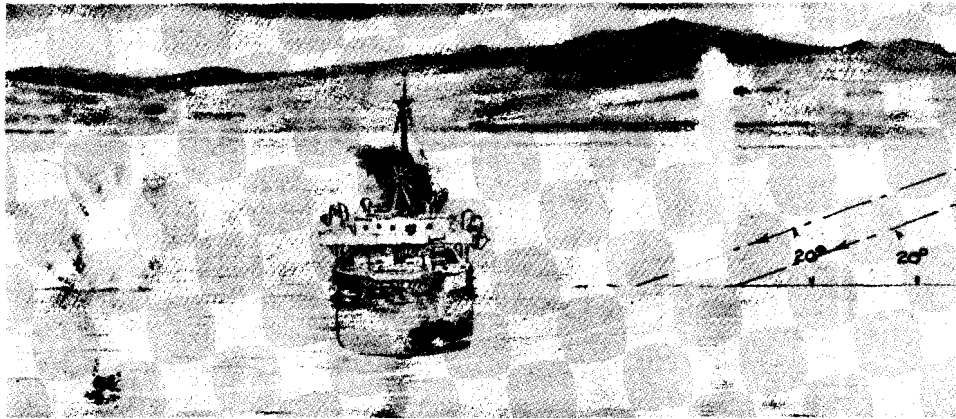


FIG. 72. Action of DDR-4 fuze (Base Fuze Mk 166 Mod 0) in 5.0-in. HVAR with 5.0-in. Sphere-ogive Head Ex-1 on (a) hitting target above waterline, (b) hitting below waterline, and (c) missing target.

either above the waterline, or below the waterline following widely varying distances of underwater travel.¹

The remaining requirements for the fuze are concerned principally with safety in handling and use, and are the same as for the PIR series of base fuzes for aircraft rockets.

5.01. DESCRIPTION OF DDR-3A, DDR-4, AND DDR-4A FUZES.—The DDR-3A fuze has been designated by the Navy as the Base Fuze Mk 162-0. The DDR-4 and DDR-4A fuzes have been designated as the Base Fuze Mk 166-0 and the Base Fuze Mk 166-1, respectively.

¹ The DDR is frequently referred to as a "water-discriminating" fuze. This is not too inaccurate, but is certainly unfortunate because of the implication that the fuze is water-discriminating in the same sense as is the AIR-9 fuze, and because of the faulty ideas as to tactical applications that may be derived from this implication.

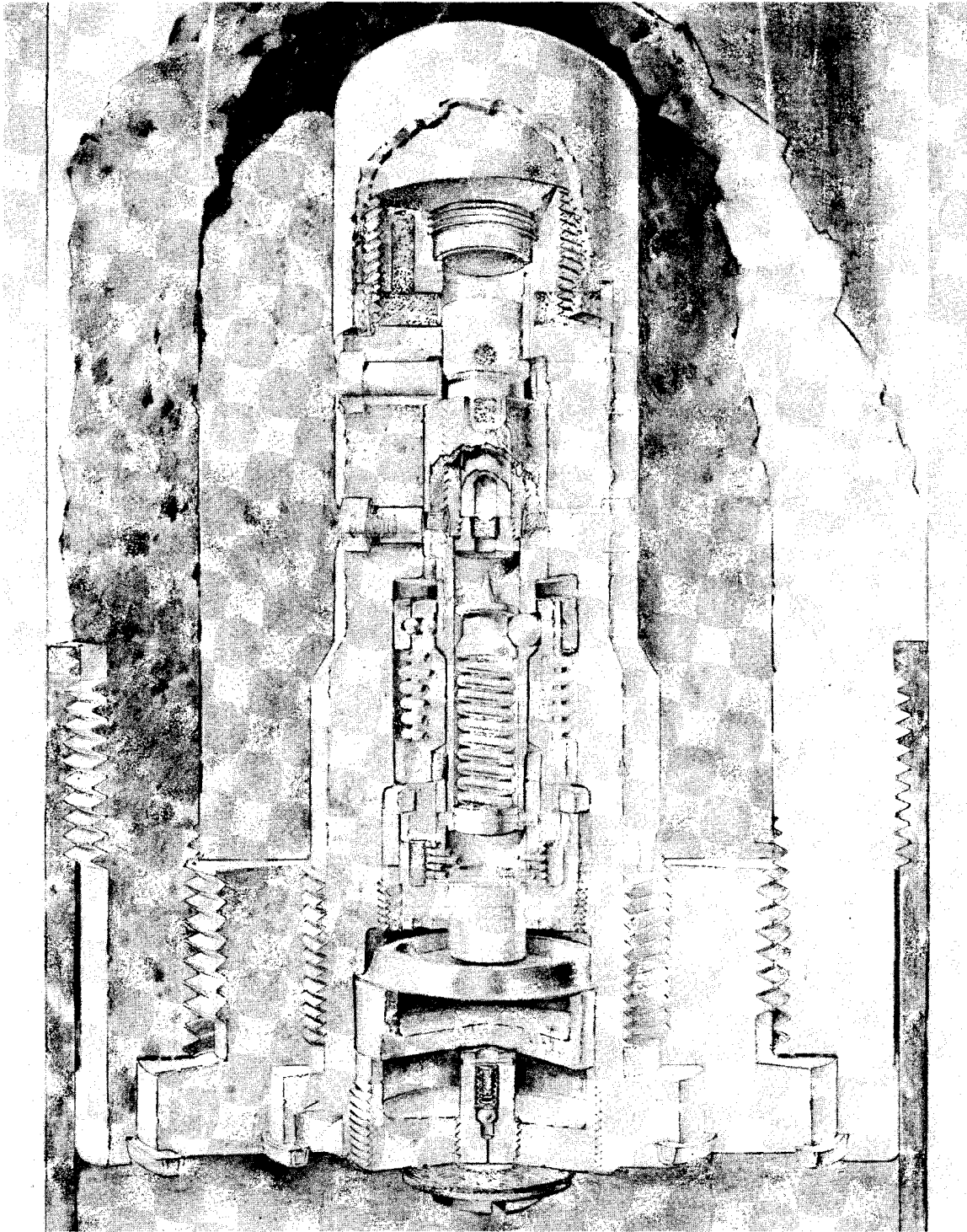


FIG. 73. DDR-4 fuze installed in 5.0-in. Head Mk 2 Mod 2.

5.011. ROCKET BASE FUZE Mk 162 MOD 0 (DDR-3A)

Rockets in which used

11.75-in. Aircraft Rocket, with 11.75-in. Motor Mk 2 and 11.75-in. Head Mk 4

11.75-in. Aircraft Rocket, with 11.75-in. Motor Mk 1 and 11.75-in. Head CIT Mdl 2 (sphere-ogive) or 11.75-in. Head Mk 2 (both with minor changes in base fuze liner)

Dimensions and weight

External thread : 2.75"-14NS-2

Weight : 4.9 lb

Materials used

Body : cold-rolled steel, AISI 1137

Detonator plunger, trigger block, trigger latch : hardened AISI A4150 or equal

Explosive components

Percussion primer, 0.01-sec pyrotechnic delay and detonator from TDF Mk 20 (projectile base fuze)

Lead-out : tetryl

Lead-in : tetryl

Booster : tetryl (25 gm approximately)

5.012. ROCKET BASE FUZES Mk 166 MOD 0
AND Mk 166 MOD 1 (DDR-4 AND DDR-4A)

Rocket in which used

5.0-in. High-Velocity Aircraft Rocket, with 5.0-in. Motor Mk 1 or Mk 2 and
5.0-in. Head Type Ex-1 (CIT Model 31) or 5.0-in. Head Mk 2 Mod 2

Dimensions and weight

External thread: 2.125"-12NS-2

Weight: 3.9 lb

Materials used

Same as in Mk 162 Mod 0

Explosive components

Mk 166 Mod 0: Sensitive primer from TDF Mk 28 (projectile base fuze).
No pyrotechnic delay. Remainder of explosive train same
as Mk 162 Mod 0.

Mk 166 Mod 1: Percussion primer from TDF Mk 20. Pyrotechnic delay—
unsettled.¹ Remainder of explosive train same as Mk 162
Mod 0.

The three modifications of the DDR fuze (5.01) differ only in relatively minor details, which will be treated in 5.016. A description of the fuze follows:

5.013. GENERAL.—The mechanism is contained in the fuze body, the head of which contains a double chamber formed by the plug, the baffle cup, and the diaphragm. Gas from the rocket motor, utilized in arming the fuze, enters these chambers through the inlet valve. The diaphragm seals off the remainder of the fuze body cavity. Immediately beneath the diaphragm an aluminum alloy arming sleeve is held in position by a shear wire. A pin through the arming sleeve engages the rotor, which is spring-loaded by a torsion spring. The axial slots inside the rotor, which engage the arming-sleeve pin, also engage the detonator-plunger pin through the detonator plunger, and two pins pressed in the trigger block engage the rotor. A spring-loaded firing pin is contained in the detonator plunger, to which is attached the detonator case containing the primer, the pyrotechnic delay (if one is used), the detonator, and the tetryl lead-outs.

In the *unarmed* position these lead-outs are so oriented that the detonator-plunger assembly must be rotated 90° and also moved forward to line up the lead-outs with the lead-ins housed in the fuze body. In the *unarmed* position the detonator-plunger assembly is constrained from moving forward by the stop pins in the side of the fuze body. The locating pin in the fuze body serves to orient the detonator-plunger assembly and rotor-cap assembly with respect to the fuze body. The spring-loaded firing pin is held cocked by lock balls, which are held in place by the trigger block. The trigger spring is compressed between the trigger latch and a shoulder on the trigger block. The trigger-latch balls, bearing against the detonator plunger and a groove in the trigger latch, lock the trigger latch with

¹ BuOrd desired to develop a new fixed delay for this fuze. However, the 0.01-sec pyrotechnic delay from the TDF Mk 20 can be used.

respect to the trigger block.¹ The closing plug serves to close and obturate the end of the fuze body cavity, and the magazine containing a tetryl booster pellet covers the end of the fuze body.

5.014. MECHANISM OF ARMING.—The fuze is armed by gas from the rocket motor, which enters the fuze through the inlet valve. Residue associated with burning of the propellant is filtered out by the inlet-valve filter, which is made of meshed Inconel wire. Gas entering through the inlet orifice impinges on the inlet-valve ball, forcing it forward off its seat and compressing the inlet-valve spring, thus permitting the gas to enter the first pressure chamber slowly. The gas is then permitted to flow still more slowly into the second pressure chamber through a smaller orifice drilled in the baffle cup. When the pressure in the second chamber reaches a value of approximately 525 lb/in.² the diaphragm collapses, forcing the arming sleeve forward and shearing the shear wire. This frees the arming sleeve as well as the rotor, which the arming sleeve engages by means of the arming-sleeve pin, and permits the torsion spring to turn the rotor. The rotor, which also engages the detonator-plunger pin and the trigger-block locating pins, thus rotates the detonator-plunger and trigger-block assembly 90° until the rotor is stopped by the rotor-stop pin. The lead-outs in the detonator case are then lined up along the axis of the fuze with the lead-ins in the fuze body, but are still offset with respect to them along the fuze axis. Slots in the end of the detonator plunger and the stop pins in the body are also aligned by the rotation, so that the detonator-plunger and trigger-block assembly is free to move forward under the action of creep force until the trigger block rests against the shoulder in the fuze body (see Fig. 77).

The time at which the gas pressure in the second pressure chamber reaches the arming pressure value of 525 lb/in.² is dependent upon the pressure of the propellant gas in the rocket motor, which in turn depends on initial propellant temperature. As soon as burning of the propellant has ceased, the inlet-valve ball closes the inlet orifice, trapping the gas in the fuze pressure chamber. Since at this point the pressure is higher in the first chamber than in the second, the pressure in the second continues to rise until the pressures in both chambers are equalized. Thus, if burning of the propellant should cease before the arming pressure is attained in the second chamber, closing of the inlet valve would permit arming to be accomplished after the end of normal burning of the propellant. Arming after the end of burning may often occur at high propellant temperatures.

5.015. MECHANISM OF FIRING.—The arming operation involves the following steps: (1) rotation of the detonator-plunger and trigger-block assembly, and (2) movement of this assembly forward by creep force to a position (shown in Fig. 77) where the slots in the detonator plunger engage the stop pins. When these steps are completed the fuze is ready to fire on impact. Friction of the firing-pin lock balls on the trigger block, and the shoulder inside the end of the trigger block (in the DDR-4), prevent the detonator plunger from moving farther forward until impact. On impact the detonator plunger moves forward to the position shown in Fig. 78, where it is stopped by the shoulder in the fuze body adjacent to the lead-outs, and is locked by the detents. In this position the tetryl lead-outs in the detonator

¹ This latching mechanism serves mainly to simplify final assembly of the fuze.

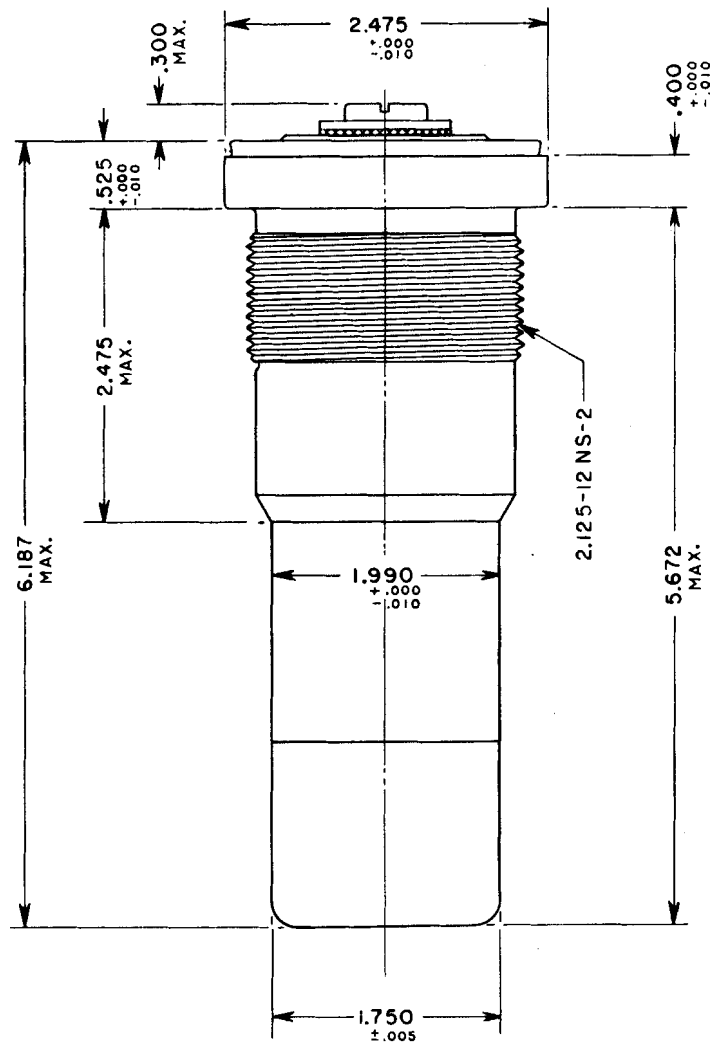
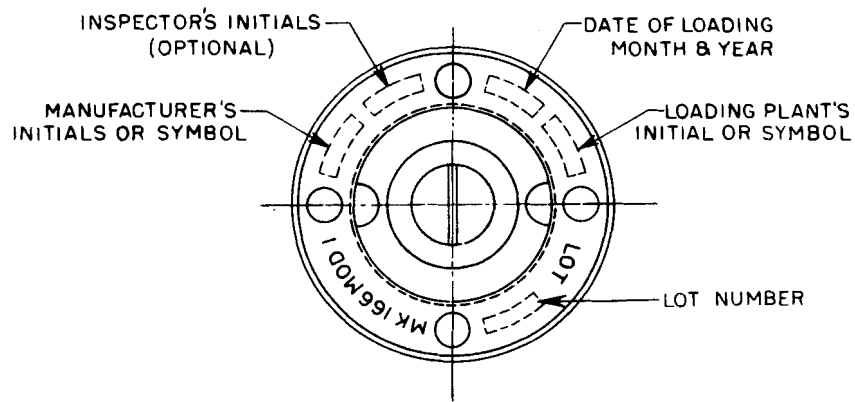


FIG. 74. Outline view of DDR-4A fuze (Base Fuze Mk 166 Mod 1).

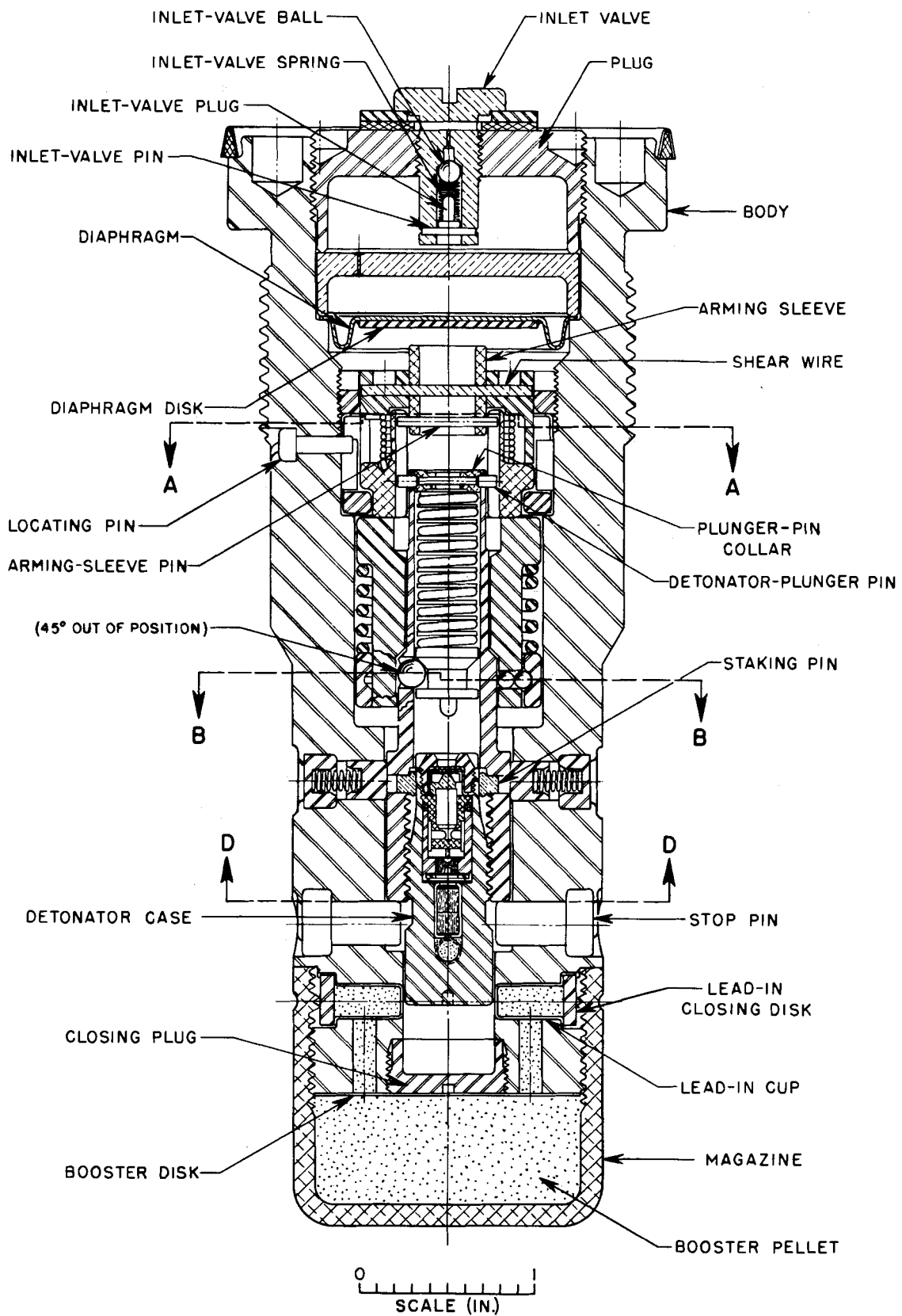


FIG. 75. DDR-4A fuze, unarmed.

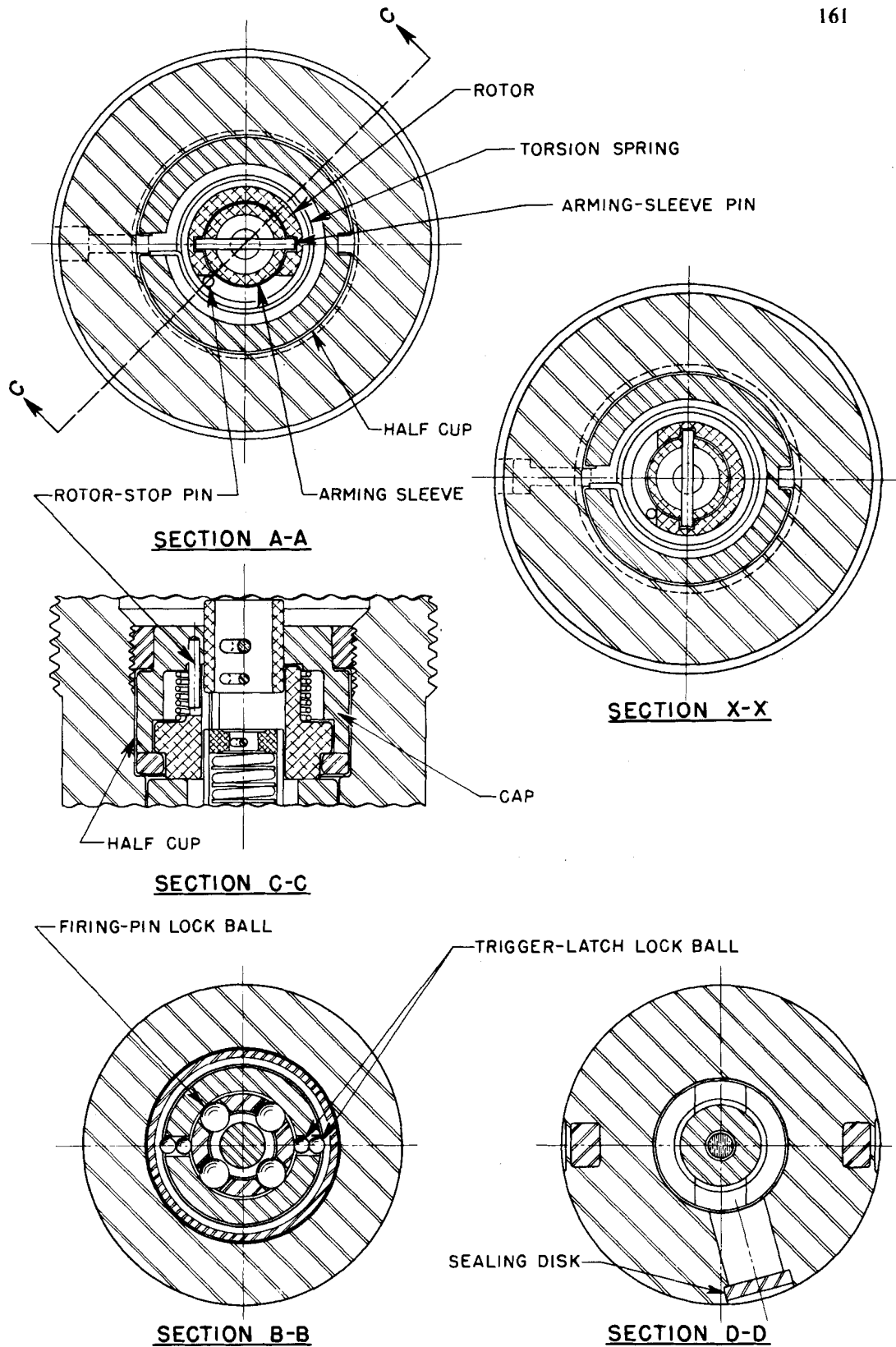


FIG. 76. Sections of the DDR-4A fuze, unarmed, and (Section X-X) fully armed as in Fig. 77.

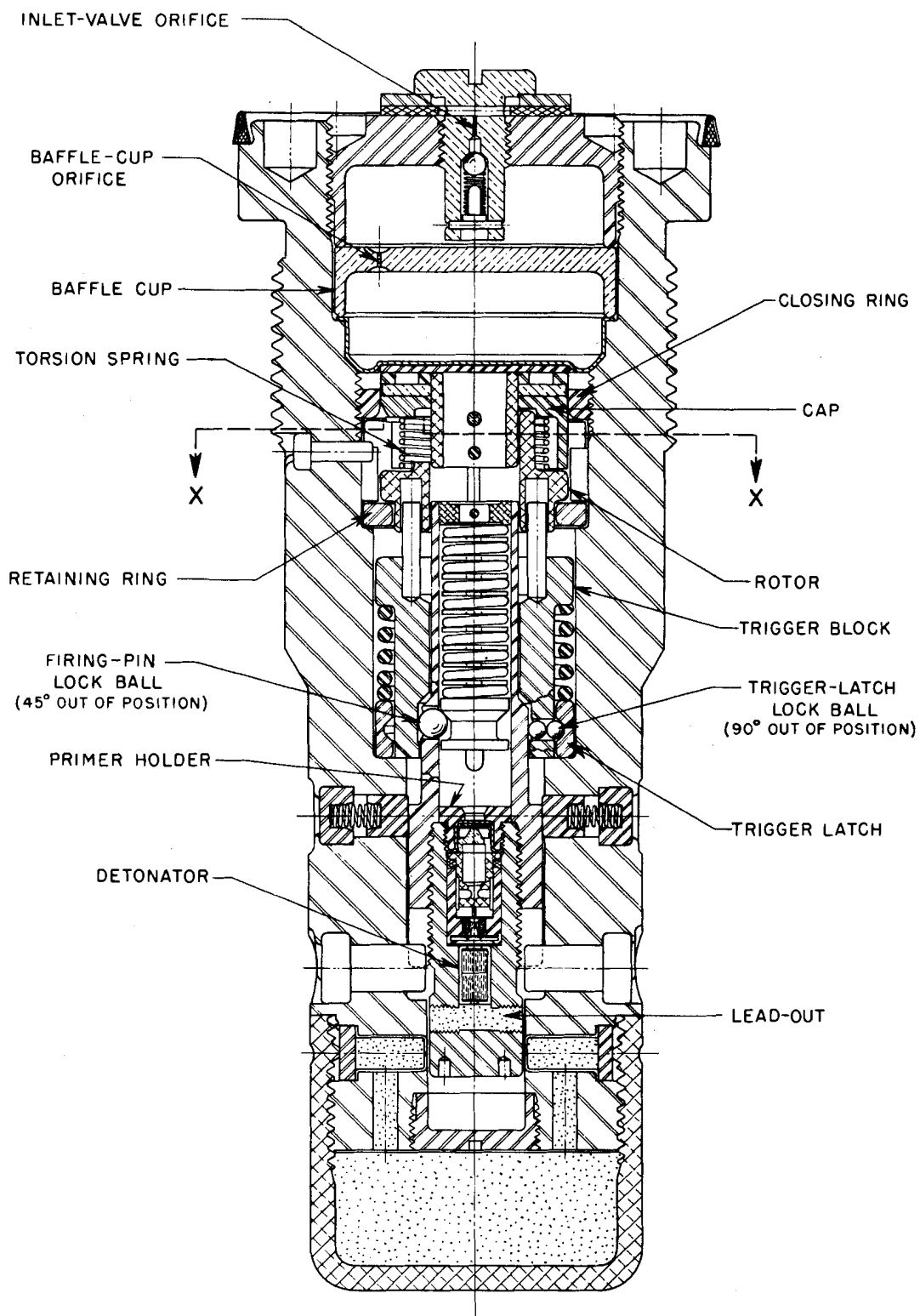


FIG. 77. DDR-4A fuze, fully armed.

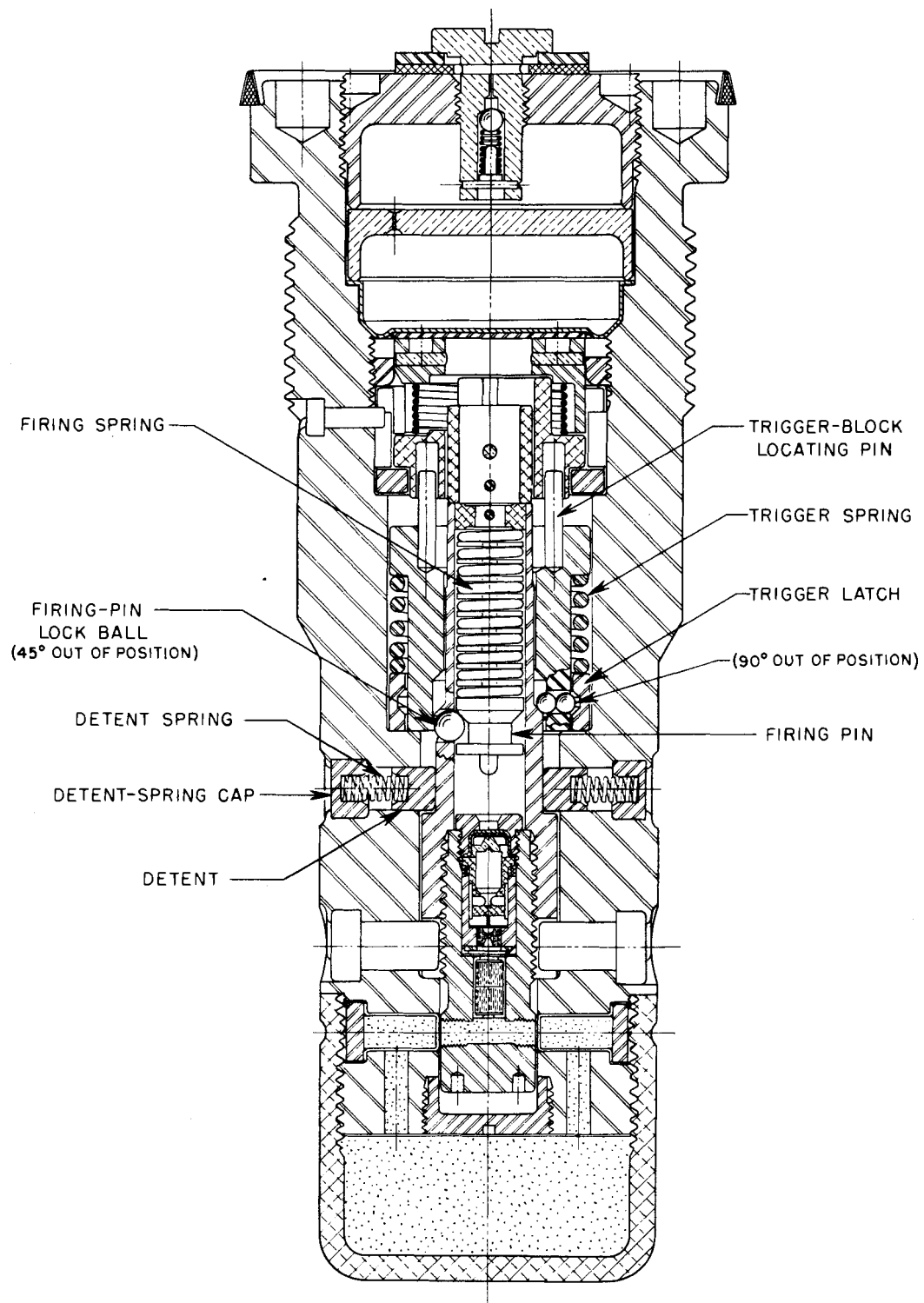


FIG. 78. DDR-4A fuze, showing position of parts on impact and during rapid deceleration.

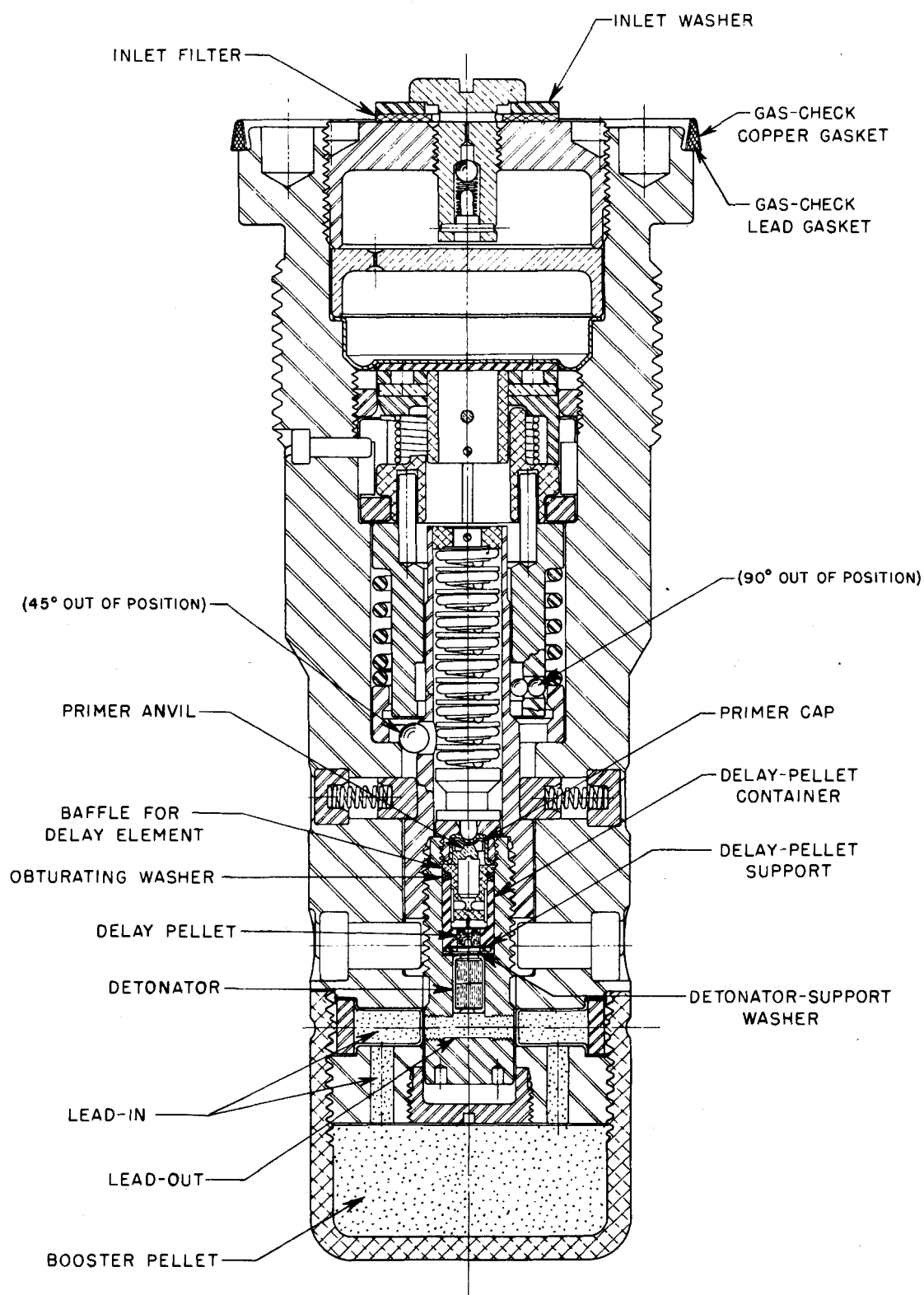


FIG. 79. DDR-4A fuze, fired.

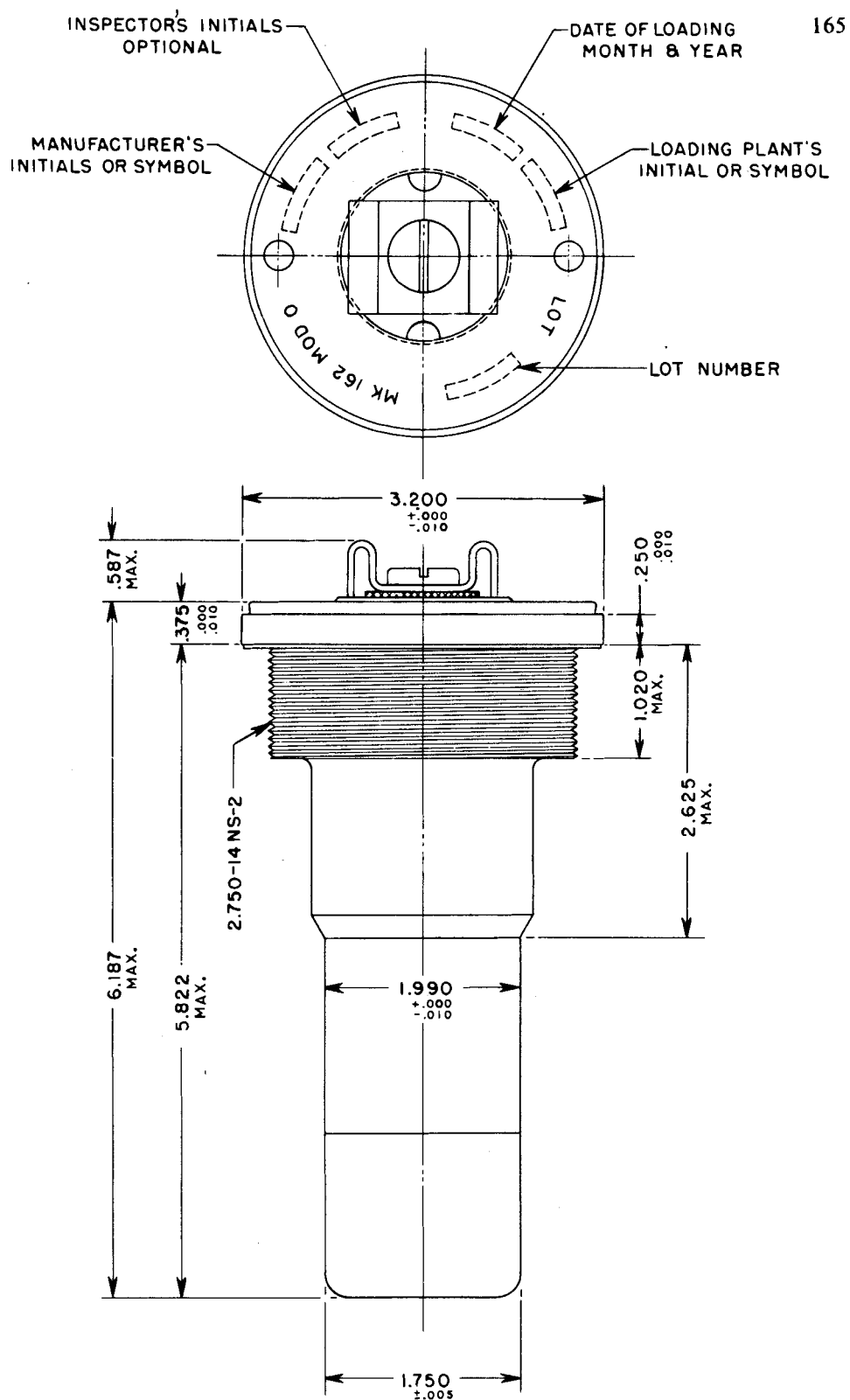


FIG. 80. Outline view of DDR-3A fuze (Base Fuze Mk 162 Mod 0).

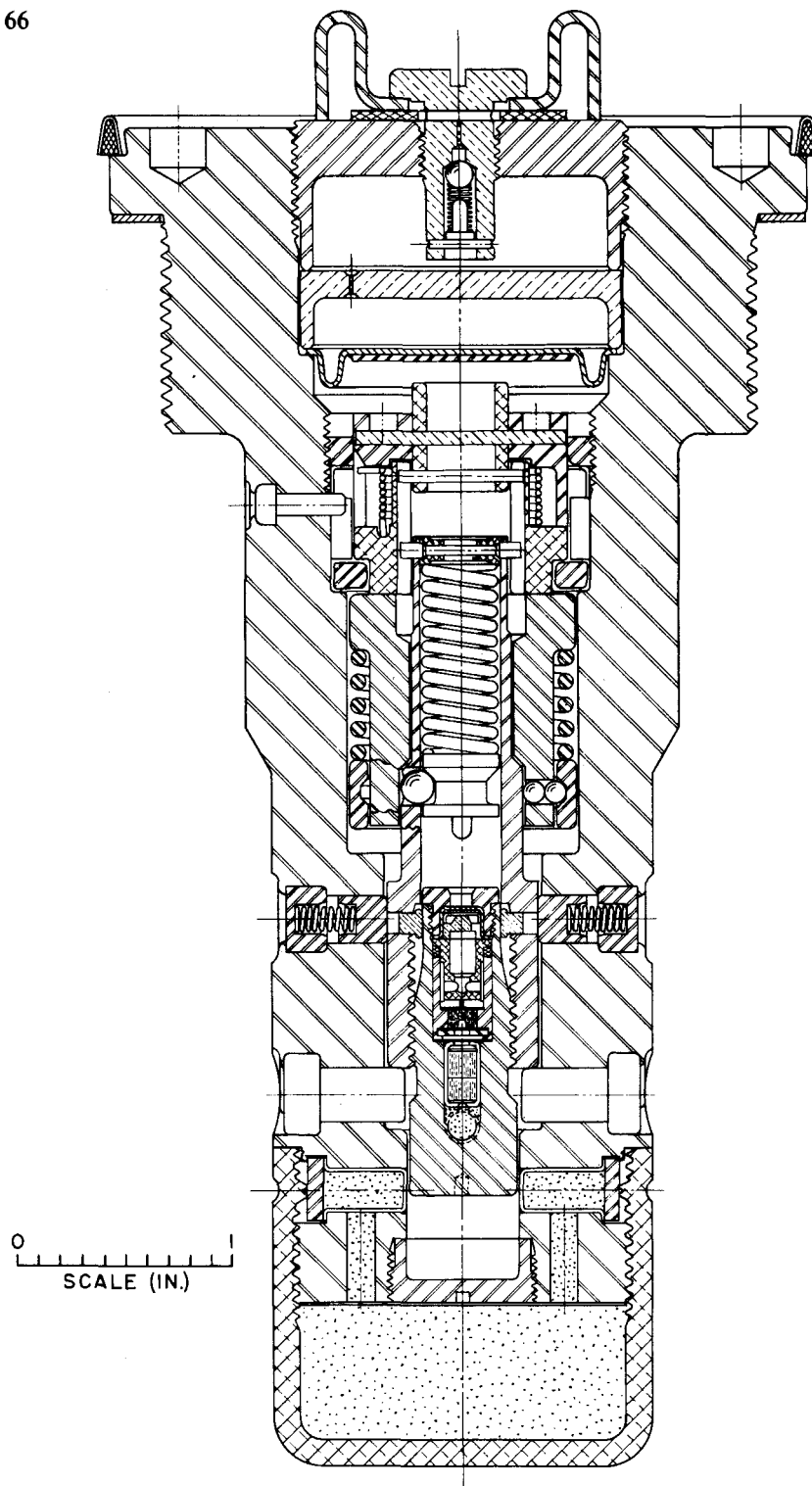


FIG. 81. DDR-3A fuze, unarmed.

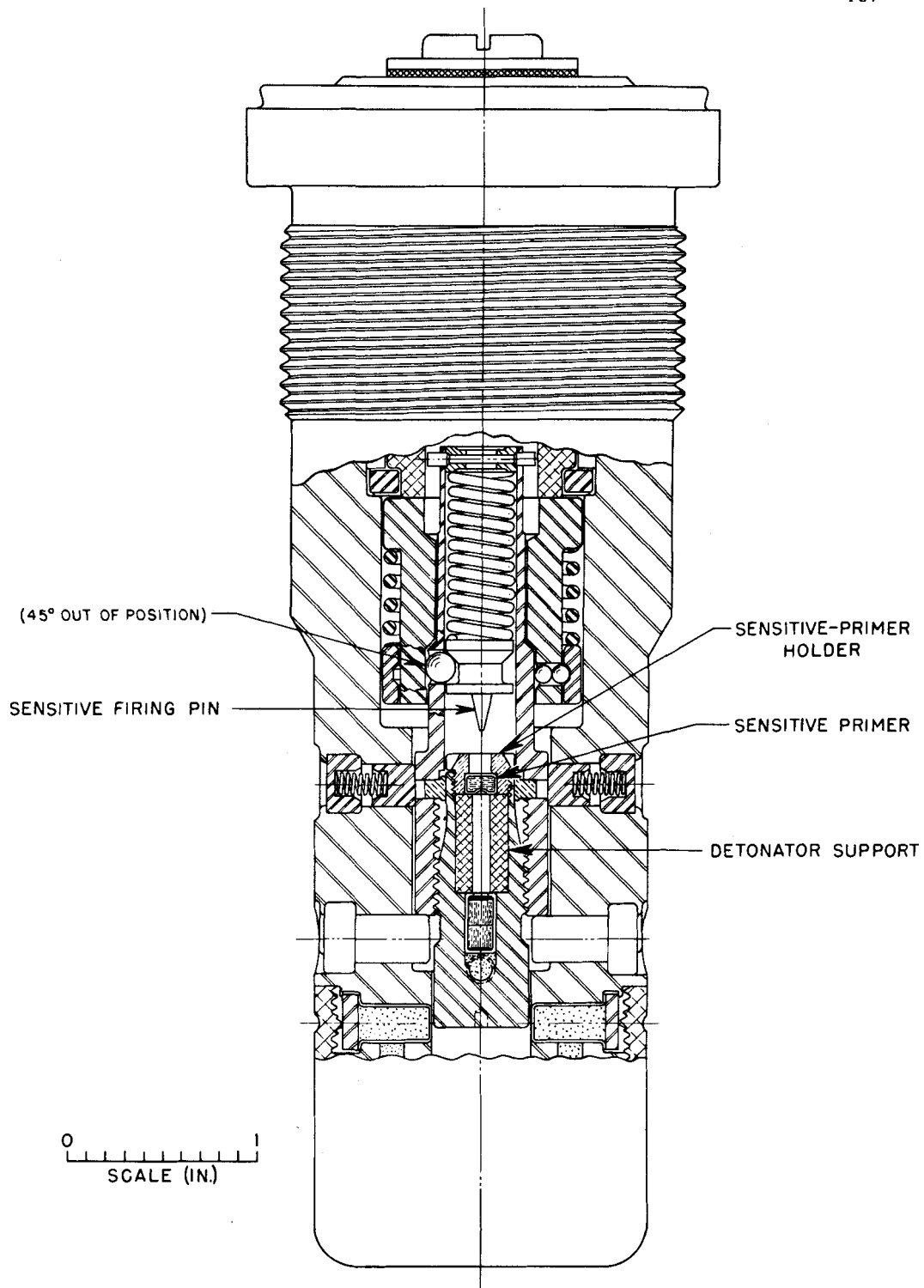


FIG. 82. DDR-4 fuze, unarmed (Base Fuze Mk 166 Mod 0).

case are lined up with the tetryl lead-ins in the fuze body. At the same time the trigger-latch lock balls fall in behind the shoulder on the detonator plunger, releasing the trigger latch, which was formerly locked with respect to the trigger block, and rendering the trigger spring active. The trigger spring is then effectively compressed between the shoulder on the trigger block and the shoulder in the fuze body cavity and tends to force the trigger block toward the rear.

As long as deceleration of the round is high the inertia of the trigger block keeps the trigger spring compressed, but as soon as the deceleration is reduced below a value determined by the strength of the trigger spring and frictional forces, the spring forces the trigger block to the rear, off the firing-pin lock balls. The balls thus released move outward and release the spring-loaded firing pin. The firing pin initiates the primer, which in turn initiates the detonator and thus causes detonation of the explosive train of the fuze and the explosive in the head.

5.016. DIFFERENCES BETWEEN THE DDR-3A AND DDR-4 FUZES.—The differences between the DDR-3A and DDR-4 fuzes (Base Fuzes Mk 162 and Mk 166) result from the differences in the rockets for which they are to be used, the DDR-3A being intended for the 11.75-in. AR with either a standard or special head, as noted in 5.011, and the DDR-4 being intended for the 5.0-in. HVAR with either of two special heads (as noted in 5.012, but see also the important note in 5.031 on the 5.0-in. Head Mk 2 Mod 2). These differences are discussed below.

1. The external thread and the corresponding largest diameter of the DDR-3A fuze are the same as those of the PIR-19 fuze, so that the two fuzes may be used interchangeably in the 11.75-in. Head Mk 4. On the other hand, since use of this large diameter has been found to weaken the base adapter for the 5.0-in. head considerably, the external thread of the DDR-4 was made as small in diameter as possible consistent with the strength required in the fuze itself.

2. The simpler inlet washer works satisfactorily with the 5.0-in. HVAR motor, so that this is used for the DDR-4. However, the 11.75-in. motor requires the inlet bracket as used for the DDR-3A.

3. The burnt velocity of the 11.75-in. AR is considerably less than that of the 5.0-in. HVAR, and the reaction time of the rocket motor is slightly shorter. The requirement that the minimum arming distance of the fuze be 400 ft necessitates that the arming time of the DDR-3A fuze be made considerably greater than that of the DDR-4 fuze. This is done by making the secondary or baffle-cup orifice considerably smaller in the DDR-3A than in the DDR-4.

4. The 11.75-in. AR experiences a smaller deceleration under water than does the 5.0-in. HVAR (see 5.03). The trigger spring of the DDR-3A fuze is therefore not as strong as that of the DDR-4.

5. The creep force or air-drag force on the 11.75-in. AR is much less than that on the 5.0-in. HVAR (see Table 1, Ch. 1). The friction between the firing-pin lock balls and the inside surface of the trigger block is sufficient to overcome the "creep" force in the 11.75-in. AR, but not in the 5.0-in. rocket. The DDR-4 trigger block, therefore, has a reduced inner diameter (Fig. 83) at the forward end to provide further insurance against air bursts (premature firing of the fuze just after burning of the rocket motor is completed) by requiring the firing-pin lock balls to move in, and the firing pin to move back against the firing spring, before they can

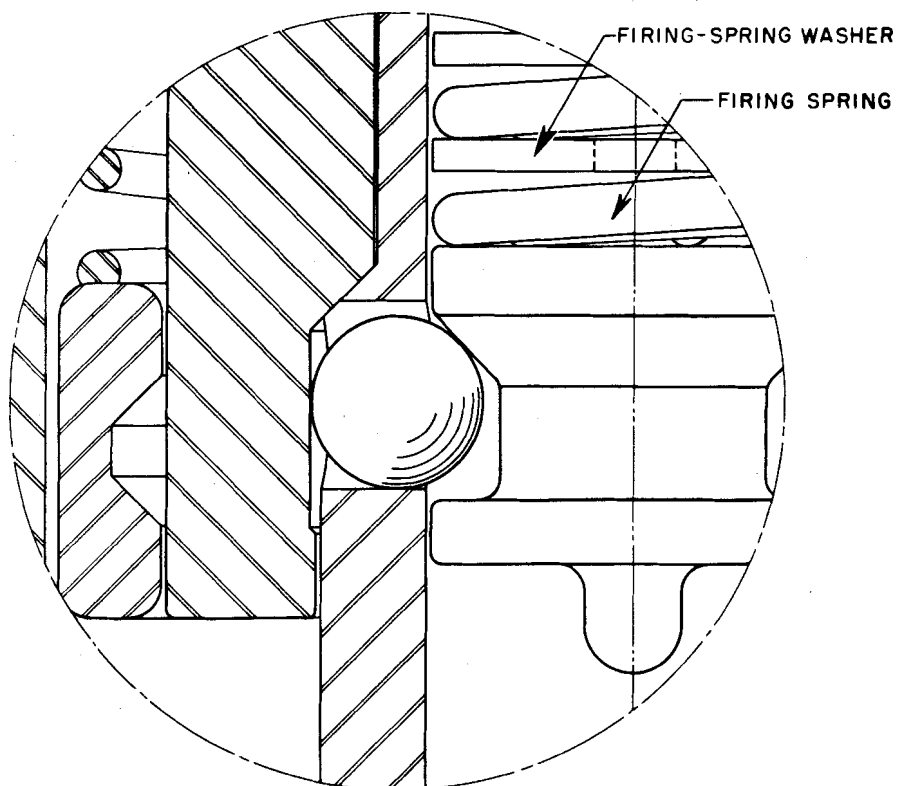
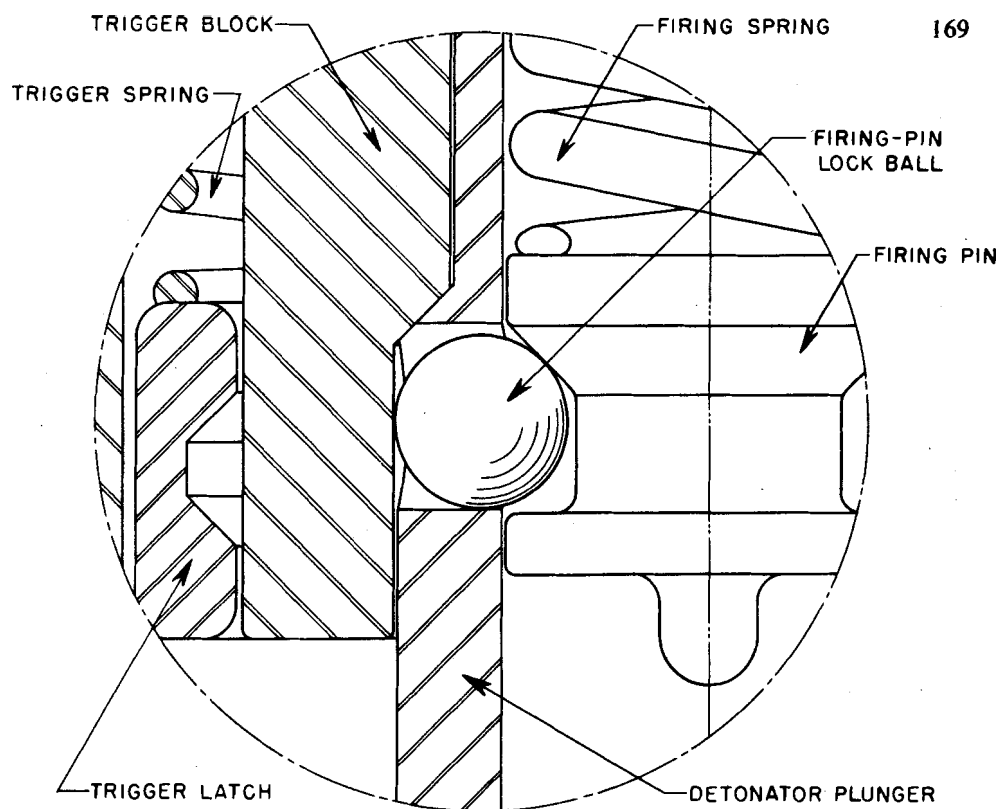


FIG. 83. Comparison of trigger blocks of DDR-3A (above) and DDR-4 (below).

move very far forward with respect to the detonator plunger, thus supplementing the restraining frictional forces.

6. The DDR-4A is used in heads that will withstand much heavier plate impacts than any 11.75-in. head now in use or known to be contemplated (0.6-caliber plate as against 0.2-caliber). For this reason, a sturdier firing spring (see 5.026) is used in the DDR-4A than in the DDR-3A.

7. As can be seen from the assembly drawings (Figs. 81 and 82), the DDR fuze can be loaded with either a pyrotechnic delay or an instantaneous detonator with a minimum number of changes in the inert parts. A percussion-type firing pin is required if a delay is to be used, but otherwise a stab-type firing pin is desirable because of the greater sensitivity of the stab-type primer. The only other difference is in the loading, and the parts involved in the loading, of the detonator case.¹ The fuze is used with the delay in projectiles, such as the 11.75-in. AR, that do not attain optimum penetration of the target during the normal mechanical delay, or with heads that will withstand impacts heavy enough to reduce the magnitude of this normal delay to the point where it is not sufficient in itself.

5.018. UNDERWATER TRAVEL.—The distance traveled under water before detonation by a rocket fuze with the DDR is determined (for a given rocket) primarily by the strength of the trigger spring. Frictional forces will reduce the effective strength of the spring, and the behavior of the round itself may depart somewhat from that predicted by the theory (see 5.03). The trigger spring will just overcome a deceleration of 50 to 60 g for the DDR-3A, or a deceleration of 80 to 95 g for the DDR-4 or DDR-4A. The frictional forces, which must be subtracted from these figures, will be about 15 to 20 g, and in extreme cases as little as 10 g or as much as 30 g.

5.02. PERFORMANCE OF DDR-3A, DDR-4, AND DDR-4A FUZES.—A considerable number of these fuzes, both from experimental lots made solely for testing purposes and from the first quantity production, have been tested in various ways. From the results it may be stated that a properly made, assembled, and loaded fuze will perform as it is supposed to, with a satisfactorily small percentage of failures. However, the complex nature of the fuze requires that a considerable variety of tests be made to establish the complete details of the fuze performance. The more important of these tests have been performed, but the end of the war and consequent termination of fuze activities at CIT prevented the completion of some of the additional tests that appeared desirable.

5.021. FORTY-FT DROP TEST; JOLT-AND-JUMBLE TEST.—The mass of metal that the shear wire must hold in place under longitudinal accelerations is much smaller in the DDR than in the PIR type of fuze. This results in an appreciable safety factor in the drop test and the jolt-and-jumble tests (see Ch. 1). Indeed, the DDR has been shown to pass these tests when only half the specified length² of smaller diameter (0.051 in. against 0.058 in. standard) shear wire is used.

On the other hand, a considerable mass of metal is restrained from rotating by

¹ The use of a pyrotechnic delay is indicated by a letter *A* suffixed to the model number. For example, the DDR-4 contains an instantaneous detonator, but the DDR-4A contains a delay.

² In this case shearing occurs at only one place.

the shear wire. No difficulty has been experienced in the jolt-and-jumble test because of this, but it is possible that the shear wire could become either wholly or partially severed by excessive torque applied accidentally during assembly and loading. Special procedures for loading and assembly have been specified, and it is believed that these will be adequate, especially since a rather high torque (85 in.-lb) is required to sever the shear wire. But further precautions may prove necessary.

5.022. DETONATOR SAFETY.—The DDR fuze is detonator-safe when completely unarmed.¹ However, when the detonator is fired with the lead-outs lined up with the lead-ins longitudinally, but rotated 90°,² the lead-ins occasionally will burn out. This would probably result in the high-explosive filler of the head igniting and burning out. The lead-ins have not been observed to detonate under these conditions, however.

5.023. ARMING DISTANCE.—The arming time has been determined by assembling the fuze with the appropriate rocket motor, firing the motor statically, and observing either the pressure on the diaphragm of the fuze or the time at which an electrical switch is closed by severing of the shear wire. The arming distance is then calculated from this time, assuming linear acceleration of the rocket.

The DDR-4 or DDR-4A in the 5.0-in. HVAR will arm at about 450 to 580 ft from the launcher (see Fig. 84). The arming distance of the DDR-3A in the 11.75-in. AR has not been determined: it is probably considerably greater than 400 ft, however.³

5.024. PREMATURES.—Tests have been performed to determine the minimum sensitivity at which the DDR-4 will premature (fire at the end of burning of the rocket) in the 5.0-in. HVAR.⁴ The maximum sensitivity allowed in production fuzes Mk 166 was given as 0.4 times this minimum. However, the field testing methods available were not entirely satisfactory, so that further testing is considered desirable. Air-drag forces on the 11.75-in. AR are so small that it is considered virtually impossible to make a DDR-3 sensitive enough to premature in this rocket. The maximum sensitivity allowed in production fuzes Mk 162 was therefore set arbitrarily at a little less than twice that allowed for the Mk 166.

5.025. UNDERWATER AND UNDERGROUND PERFORMANCE.—A considerable number of DDR fuzes have been fired into water, in both the 5.0-in. HVAR and the 11.75-in. AR. The distances traveled under water before detonation have corresponded as closely as could be expected with that predicted by the theory (see 5.032), and the results have been very satisfactory.⁵

Not so many fuzes have been fired for ground impact. However, it is also cer-

¹ CIT/OIC 12.1, 21 September 1945.

² Such a situation could occur on very heavy impacts during burning of the rocket—that is, before the fuze was armed.

³ On the basis of tests reported in CIT/OIC 12.1, 16 October 1945, a secondary orifice diameter of 0.0075 in. has been recommended.

⁴ CIT/PMC 2.74, 4 March 1945, Part 2, pp. 6-7; CIT/PMC 2.84, 24 June 1945, Part 2, pp. 4-6; CIT/PMC 2.87, 5 August 1945, Part 2, pp. 1-2.

⁵ There were no fuze failures at all in the last 126 fuzes fired by CIT. These were mostly from production.

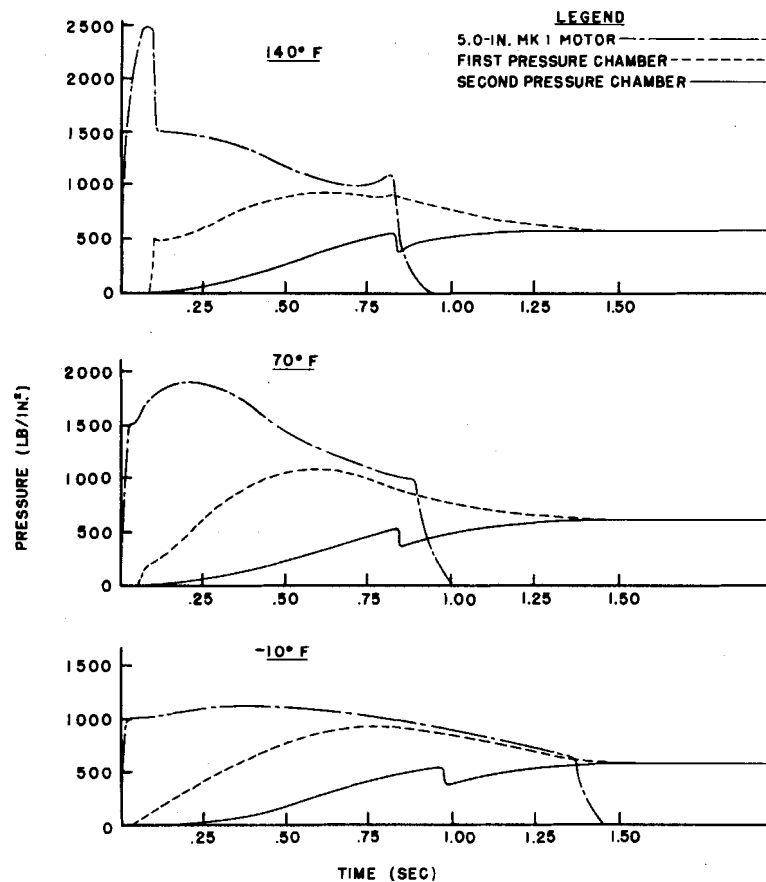


FIG. 84. Records of pressure vs. time from static firings of 5.0-in. Rocket Motor Mk 1 with DDR-4 fuze (Base Fuze Mk 166 Mod 0) at three propellant temperatures. Arming of fuze occurs at point where pressure in second pressure chamber (full line) suddenly drops.

tain in this case that the fuze will perform properly so long as the rocket itself behaves, that is, so long as the deceleration is essentially longitudinal (along the principal axis of the rocket).

5.026. PERFORMANCE ON PLATE.—Very little information on the plate sensitivity of the DDR fuze has been obtained. However, it seems likely that the DDR-4 or DDR-4A, when installed in a 5.0-in. HVAR, will fire on plate as light as $\frac{1}{4}$ -in. mild steel at obliquities from 0° to about 60°. The DDR-3A is more sensitive than this, but, on the other hand, the rocket in which it is used (11.75-in. AR) is much heavier, so that thicker plate would be required to fire it.

The mechanical delay in firing on light plate may be as great as 0.015 sec, and will probably average about 0.010 sec.

Tests in which partially loaded DDR fuzes, with primer and delay element only live-loaded, were assembled in 5.0-in. HVAR, using inert-loaded 5.0-in. Rocket

Heads Model 35 or 5.0-in. Rocket Heads Mk 2 Mod 2¹ and fired against 2-in. and 3-in. STS, were generally satisfactory, once a few minor design changes had been made. The only serious difficulty encountered, aside from that resulting from the quality of steel for the fuze body available during wartime, was with the firing and trigger springs. On such heavy impacts these springs lose much of their strength (about half after impact with 2-in. STS at 40° obliquity), and are distorted, the departure from straightness (that is, true cylindrical shape) being sufficient to cause considerable friction between the springs and the parts within which they operate. This is most serious in the case of the firing spring, which will fire a percussion primer after such impacts only about 50 per cent of the time, although it will fire the more sensitive stab-type primer quite consistently. A series of conical springs separated by steel washers, which is used for the firing spring in the DDR-4A (Mk 166 Mod 1), is believed to be a satisfactory solution. These springs are so wound that they compress flat under a sufficient load, and thus each coil is supported by a comparatively soft steel washer rather than by a coil of hard spring wire, as in the helical spring. For this reason they lose less of their strength on impact and are not subject to the distortion mentioned above.

The mechanical delay in firing on heavy plate is quite small. When fired in the 5.0-in. HVAR against $\frac{3}{4}$ -in. to 2-in. STS at 30° obliquity the DDR-4 fires with a delay of about 0.0015 sec, most of this consisting of the time required for the trigger block to move back. On heavier plate or 2.0-in. plate at higher obliquities the delay becomes less. In this case the impact forces are so high that the firing pin forces the restraining lock balls apart and strikes the primer during impact. No pyrotechnic delay is included in the DDR-4, and as a result the head will be detonated in the plate. Since this is undesirable, a very short delay (0.002 to 0.006 sec) is specified for the DDR-4A. This latter fuze, because the series of conical firing springs is slightly heavier than the single helical spring, will fire *mechanically* during impact (that is, in the plate) on 2-in. plate at 0° obliquity, but will fire mechanically behind the plate on $1\frac{1}{2}$ -in. plate at 0° obliquity.

5.027. POSSIBLE FUZE FAILURES ON PLATE.—If a rocket containing the DDR fuze should strike steel plate at a great enough obliquity to ricochet (about 60°), the back end of the rocket head may be badly deformed. On heavy plate this deformation of the head may be great enough to cause considerable deformation of the fuze and thus prevent it from firing, since the trigger block cannot move all the way back. However, since such a rocket would not in general be useful, having ricocheted off the target rather than penetrated into it, this type of fuze failure is not regarded as serious.

5.03. UNDERWATER BEHAVIOR OF AIRCRAFT ROCKETS.—The underwater behavior of rockets is discussed in several special reports.² Here we shall mention only such features of this behavior as directly influence the performance of the DDR fuze.

¹ The 5.0-in. Head (CIT) Model 35 is the 5.0-in. Special Common Projectile modified for use with a 5.0-in. Rocket Motor Mk 1 or 2. The 5.0-in. Head Mk 2 is the Navy equivalent of the Model 35.

² *Underwater Behavior of 3.5-in. Aircraft Rockets*, CIT/JBC 23, I. S. Bowen, 6 December 1943; *Further Investigations of the Underwater Behavior of Aircraft Rockets*, CIT/JBC 27 (OSRD Report No. 2152), I. S. Bowen, 26 June 1944; *Underwater Behavior of the 11.75-in. Aircraft Rocket*, CIT/IPC 65, I. S. Bowen, 25 October 1944.

5.031. STABILITY.—Stability of the rocket, either under water or under ground, is, of course, absolutely essential to the proper performance of the DDR fuze, since the longitudinal deceleration, to which the fuze responds, will decrease uniformly when the rocket is stable, but will oscillate rapidly through a wide range of both positive and negative values if the rocket is not stable.¹

In general, a rocket may be unstable for either of two basic reasons: (1) the nose shape or the proportions of the complete rocket are such that it is intrinsically unstable, or (2) the complete rocket may be stable but the forces on it may be such as to cause separation of the motor and head, the head by itself being then almost inevitably unstable. It is this separation of motor and head that is observed for unstable rockets. Underwater breakup is usually caused by excessive side forces; underground breakup may also be caused by the much higher axial (nose) forces.²

Also, even if a particular design of rocket is generally stable, an individual round of this type may be unstable for any of a number of reasons. Such instability results in what might seem to be improper fuze behavior when, in fact, it is quite proper fuze behavior, the fuze firing when the longitudinal deceleration becomes small.

5.032. MAGNITUDE OF FORCES ON THE ROCKET.—The speed of a rocket moving under water may be expressed by the formula

$$V = V_0 e^{-cs} \quad (1)$$

where V_0 is the speed of the rocket at entry, c is the deceleration coefficient, and V is the speed after s feet of underwater travel. If a_r is the acceleration along the path (longitudinal acceleration),

$$a_r = \frac{dV}{dt} = \frac{dV}{ds} \frac{ds}{dt}$$

By differentiating (1) we obtain

$$\frac{dV}{ds} = -cV_0 e^{-cs}$$

Combining these with (1) we get

$$a_r = -cV_0^2 e^{-2cs} \quad (2)$$

Since the radius of curvature of the path remains essentially constant, the acceleration perpendicular to the underwater path, a_n , is

¹ The use of the DDR in unstable rockets such as the 5.0-in. HVAR with the 5.0-in. Head Mk 2 Mod 2 is ill-advised. The 5.0-in. HVAR with this head breaks up almost immediately on ground impact and the fuze fires mechanically after about 5 ft of underground travel. Since the peculiar advantages of the DDR fuze are thus lost entirely, the conventional and more easily manufactured impact-firing base fuze is the proper fuze to use. The Mk 2 Mod 2 head is probably unstable under water, also.

² Underground erosion of the rocket nose, especially if it is made of a comparatively soft metal, may destroy the nose shape and thus the stability of the rocket.

$$a_n = \frac{V^2}{R} = \frac{V_0^2 e^{-2cs}}{R} = -\frac{a_r}{cR} \quad (3)$$

Representative values of a_r and V are listed in Table 1. The values for the initial deceleration can be regarded only as a probable lower limit for the actual initial deceleration. The remaining values for a_r must be regarded as only approximate. Uncertainties in the experimental determination of c and variations in the behavior of individual rounds as well as uncertainties in the theory itself are such that the calculated a_r may differ from the true mean value by a considerable amount. These theoretical values are still very useful, of course, in predicting the behavior of the DDR fuze under various conditions.

TABLE 1. Values of deceleration and velocity.

ROCKET TYPE AND DESCRIPTION	V_0 (ft/sec)	s (ft)	$-a_r$ (g)	v (ft/sec)
11.75-IN. AR* WITH 11.75-IN. MOTOR MK 2, 11.75-IN. HEAD MK 4, AND DECELERATION COEFFICIENT $c = 0.0049 \text{ ft}^{-1}$	1300	148	60	630
	1300	167	50	570
	1300	190	40	510
	1300	219	30	445
	1300	238	25	405
5.0-IN. HVAR† WITH 5.0-IN. MOTOR MK 1 OR 2, 5.0-IN. HEAD TYPE EX-1 (CIT MODEL 31), AND DECELERATION COEFFICIENT $c = 0.0053 \text{ ft}^{-1}$	1700	160	90	728
	1700	168	80	697
	1700	180	70	656
	1700	195	60	605
	1700	212	50	552
	1250	110	80	697
	1250	122	70	656

* Radius of curvature of underwater trajectory = 500 ft.

† Radius of curvature of underwater trajectory = ∞ .

The forces acting on the rocket during *underground* travel are much larger than the underwater forces. In this case, although the theory may give a rough picture of what a certain rocket will do, particular details must be obtained by actual firing, and the effect of variations in soil density, etc. is such that even then no generally applicable data can be obtained. The deceleration coefficient, c , of a projectile traveling under water is given by

$$c = \frac{DA\rho}{2M} \quad (4)$$

in which A and M are the cross-sectional area and mass, respectively, D is a constant depending on the shape of the projectile, and ρ is the density of the medium through which it is traveling. For a given projectile D , A , and M are constants, and if (4) is assumed to hold for underground travel we may write

$$\frac{c_{\text{ground}}}{c_{\text{water}}} = \frac{\rho_{\text{ground}}}{\rho_{\text{water}}} \quad (5)$$

This equation can be solved for c_{ground} , since the other quantities are known. Rough calculations based on this c show that the theory predicts about twice the greatest underground travel actually obtained in tests of the 5.0-in. HVAR with the sphere-ogive head. In deriving the equations the medium was assumed to be an incompressible fluid, which is apparently not justified for underground travel.

5.04. TACTICS.—Since the DDR fuze operates on a different principle from the usual projectile fuzes, some general comments on the tactical situations in which it might be useful are in order.

Besides the more detailed comments which follow, two general points should be noted:

1. In considering the use of the DDR in any particular tactical situation, the fundamental method of operation of the fuze must be kept in mind in some detail.

2. The fuze must *not* be expected to perform properly when used in a rocket that does not have a stable underwater or underground trajectory.

5.041. WATER-BORNE TARGETS.¹—The DDR-3A in the 11.75-in. AR will fire after traveling under water for about 200 ft on the average if the entry velocity is 1300 ft/sec. The minimum travel should be about 165 ft. The DDR-4 or DDR-4A in the 5.0-in. HVAR with the sphere-ogive head will fire after traveling under water an average of about 180 ft and a minimum of 160 ft, if the entry velocity is 1700 ft/sec. These figures are, of course, only approximate, and will increase or decrease if the entry velocity is increased or decreased. For example, if the entry velocity for the 5.0-in. HVAR is 1250 ft/sec, corresponding to a round fired from a stationary launcher at 5° QE, the fuze will fire after an average underwater travel of 120 ft, and a minimum of about 100 ft.

It is desired, of course, that the fuze fire if a target is encountered during underwater travel. This will certainly happen if the rocket traverses any appreciable air space in the target (see 5.043). For some targets there may be no such air space. For example, it is presumed that at least some ships built to carry liquid cargo can be regarded, when fully loaded, as thin steel shells with liquid both inside and out. If the steel shell of such a ship is so thin that it does not cause separation of the rocket motor and head or appreciable bending of the motor tubing,² then the fuze would not “know” that this ship was there. On the other hand, if the steel plate and structural members of the ship were heavy enough to bend the motor tubing or cause separation of the motor and head, then the round would become unstable and the fuze would fire immediately.

In the case of small, shallow-draft floating targets there are advantages in using

¹ *Underwater Behavior of the 11.75-in. Aircraft Rocket*, CIT/IPC 65, I. S. Bowen, 25 October 1944. For the 11.75-in. AR the effective areas of two typical floating targets are illustrated in Figs. 5 and 6. Only the curves drawn for a 600-ft/sec striking velocity are applicable. The curve drawn for the 11.75-in. Mk 1 or Mk 2 head has a peak at about 8° entrance angle. This should be disregarded, since it represents a hit above the waterline after the rocket has reappeared.

² No complete data are available as to what thickness of plate is necessary to do this. However, it is estimated that for the 5.0-in. HVAR about $\frac{3}{4}$ -in.-thick mild steel plate would be sufficient to cause separation of the motor and head, and that $\frac{1}{2}$ -in. plate would cause at least some bending of the motor.

an instantaneous nose fuze or an impact-firing base fuze with a very short delay instead of the DDR. The decision as to which of the three possible fuzes to use would have to be based on a detailed analysis of the particular target.

In both these cases where the DDR might not be effective it should be remembered that the rocket head will still make a hole in the target.¹

The possible variation of any particular round from the theoretical trajectory for its type of rocket must also be considered,² especially in evaluating the results of an attack.

5.042. LAND TARGETS.—The same general considerations may be applied to attacks on sunken or buried land targets as were applied to water-borne targets. A rocket with a stable underground trajectory when fuzed with the DDR will travel some distance under ground before detonating unless it emerges into air, in which case it will detonate immediately. For example, aircraft-fired 5.0-in. HVAR with the sphere-ogive head have been shown to travel some 50 ft through hard-packed clay, and about 30 ft through sand or clay that contains fair-sized pieces of rock, before detonating,³ and will probably travel up to about 75 ft through soft dry sand. The 11.75-in. AR will probably travel somewhat farther than this.

Rocks comparable in size to the rocket, or other inhomogeneities in the ground, will deflect the rocket or increase its tendency to break up, and in passing through the ground the nose of the rocket may be eroded enough to lose its shape, so that the rocket will become unstable.

5.043. MECHANICAL TIME DELAY IN FIRING.—It is apparent that an important factor in the effectiveness of the fuze is the time delay between the disappearance of the deceleration (as the rocket passes, for example, from water into the air inside a ship) and the release of the firing pin; the time delay is important because successive impacts within this time will prevent the fuze from firing until after the last of such impacts. It would thus be possible for the rocket to perforate a thin, closely-packed target completely before detonating. Some effort was made to design the fuze so that this delay would be as small as possible. It is known that when 5.0-in. HVAR fuzed with the DDR-4⁴ are fired against STS plate ranging from about $\frac{3}{4}$ in. to 2 in. thick, the time interval from the moment the rocket strikes the plate to detonation is about 0.0015 sec. Since this delay does not vary with the above wide range in plate thickness, it is concluded that the detonator plunger and trigger block both move fully forward while the rocket is still being decelerated by the plate. This deceleration lasts approximately as long as the

¹ It is known that during World War II the British considered the 25-lb solid slug head on their UP3 a useful weapon against both submarines and shipping, and that the scuttling of a large Italian liner was attributed by the newspapers (possibly with exaggeration) to these rockets.

² *Underwater Trajectories of the 3.5-in. Aircraft Rocket Model 5*, CIT/JPC 21, R. V. Adams, 10 June 1944.

³ CIT/PMC 2.84, 24 June 1945, Part 2, pp. 7-9; CIT/PMC 2.85, 8 July 1945, Part 2, pp. 3-5; *Underground Trajectory of Aircraft Rockets—Data On*; NOTS Project No. 58 AR, NOTS, IK Memorandum (14 Aug. 1945) Ass't Terminal Ballistics Officer to Experimental Operations Officer.

⁴ The DDR-4 contains no pyrotechnic delay, so that the point of detonation corresponds to mechanical firing of the fuze.

ogive of the head is in the plate, or about 0.0005 sec. The balance of the delay, 0.001 sec, then represents the time required for the trigger block to move back enough to free the firing pin. (The time required for the action of the firing pin is negligible.) If the plate is under water, with air on the far side, the time delay will be the same, since the deceleration of the rocket caused by water drag disappears as soon as the nose leaves the water. (Note that in this case the plate may be thinner than $\frac{3}{4}$ in. without affecting the delay.) For plate or any sort of partition under ground, with air on the far side, the delay will probably be the same. However, the "bubble" formed by passage of the rocket through the ground may not be so nearly perfect as that formed in water, and may cause some drag on the tail of the rocket, so that the deceleration will not disappear entirely until the whole rocket emerges into air, with the result that the delay will be slightly lengthened.

The distance traveled in this time will vary with the velocity of the rocket. It may be calculated for the 5.0-in. HVAR for a particular case by adding 0.5 ft (approximately the length of the ogive on the 5.0-in. head) to the distance traveled by the rocket in 0.001 sec. At 1600 ft/sec striking velocity the nose of the rocket will be about 2.1 ft behind the plate.

5.044. PYROTECHNIC DELAY.—A 0.010-sec delay was specified for the DDR that is to be used in the 11.75-in. AR (the Mk 162 Mod 0), since this rocket would be used against comparatively large targets, and in such cases some penetration into the target would be desired. On the other hand, since the 5.0-in. HVAR would be used against smaller targets, no pyrotechnic delay was specified initially for the Mk 166. When it was discovered later that this fuze would fire mechanically during heavy impact, the addition of a fixed delay of about 0.002 to 0.006 sec was recommended when the fuze was to be used in 5.0-in. heads that will stand up under these impacts. For heads such as the 5.0-in. sphere-ogive (CIT Model 31 or BuOrd Type Ex-1) for which the limit plate is about 1-in. STS, this additional delay might not be desirable, depending on the details of anticipated targets.

5.045. ADDITIONAL TARGETS.—In addition to attacks on water-borne targets and such land targets as dirt-covered pillboxes and bunkers, the DDR may also be useful in attacks on heavy concrete fortifications, since it will detonate the rocket at somewhere near its maximum penetration into massive concrete. To obtain maximum effectiveness the fuze should have no pyrotechnic delay. However, tests have shown that if the concrete is well reinforced and of high strength, then the 5.0-in. HVAR contains too little high explosive to cause much more damage than is caused by the impact itself. The 11.75-in. AR probably does contain enough high explosive to be useful.

It should be noted that the DDR has disadvantages, compared with an impact-firing base fuze or an instantaneous nose fuze, in attacks on small exposed targets such as tanks, trucks, antiaircraft emplacements, etc.

5.046. STABLE AIRCRAFT ROCKETS.—The following aircraft rockets are the only ones, according to available data, that have stable underwater or underground trajectories:

1. The 5.0-in. HVAR with the 5.0-in. sphere-ogive head, CIT Model 31 or BuOrd Type Ex-1, is stable both under water and under ground.
2. The 5.0-in. HVAR with the 5.0-in. Head Mk 6, when the flat shipping

plug is used in place of the conical SAP nose or Mk 149 fuze, is stable under water and probably in soft sand. In hard ground, the shipping plug is broken up on impact, and the axial forces on the rocket are sufficient to cause it to break up.

3. The 5.0-in. HVAR with the 5.0-in. Head Mk 2 Mod 2, when an appropriate windshield is used to give the head the approximate external contour of the sphere-ogive head, may be stable both under water and under ground. Only very incomplete information is available.

4. The 11.75-in. AR with the sphere-ogive head, CIT Model 2, is stable both under water and under ground.

5. The 11.75-in. AR with the 11.75-in. Heads Mk 1 or Mk 2 (all mods) is stable both under water and under ground.

6. The 11.75-in. AR with the 11.75-in. Head Mk 4 is stable under water but is not stable under ground; however, it may be expected to travel about 20 ft or possibly more under ground before the DDR fuze will fire.

The 11.75-in. Heads Mk 1 and 2 have a "skirt" that extends back into the rocket motor to increase the resistance of the rocket to breakup caused by side forces. The Mk 4 head is characterized principally by the absence of this skirt and apparently breaks up because of side forces.

5.047. DUDS.—Some consideration must be given to the problem of removing possible duds if rockets fuzed with the DDR are to be used against targets that will shortly thereafter be occupied by friendly troops.

It is not possible to tell from external examination of a DDR whether or not it is armed. If it is armed, then it will be from two to ten times as sensitive as other armed rocket base fuzes. In addition, the spring-loaded firing pin makes an extremely sensitive dud possible, although it is considered rather improbable. Any duds, therefore, should be detonated in place, except in the direst emergencies.

5.05. DDR-1 AND DDR-2 FUZES.—The DDR-1 and DDR-2 are the early models of the DDR fuze. They differ from the DDR-3 and DDR-4 principally in the mechanism involved in arming, this change having been made because it was found that on heavier impacts during burning (5.0-in. HVAR on plate an unknown amount thicker than 1-in. mild steel) the detonator plunger would be forced free of the two locking balls and the fuze would fire. Thus the requirement that the minimum arming distance be 400 ft was not satisfied.

5.051. DESCRIPTION.—The DDR-2 fuze is shown in Fig. 85. The DDR-1 differs from the DDR-2 in having the fuze body and fuze head as separate pieces, the fuze head with associated parts being very similar to that of the PIR fuzes (Mk 164, etc.). In either case the orifice sizes, arming pressure, etc. are adjusted so that the diaphragm is collapsed at about half the burning time of the rocket motor. Because of the position of the center of the detonator-plunger locking balls, setback acting on the detonator plunger tends to hold these balls in place. When setback ceases, then the springs behind the locking balls push them in until they are entirely inside the detonator plunger, leaving the latter free to creep forward until it is stopped by the cap over the trigger spring.¹

¹ Note that an impact during arming of the rocket will move the detonator plunger forward more rapidly than the lock balls can escape, and the fuze will remain unarmed.

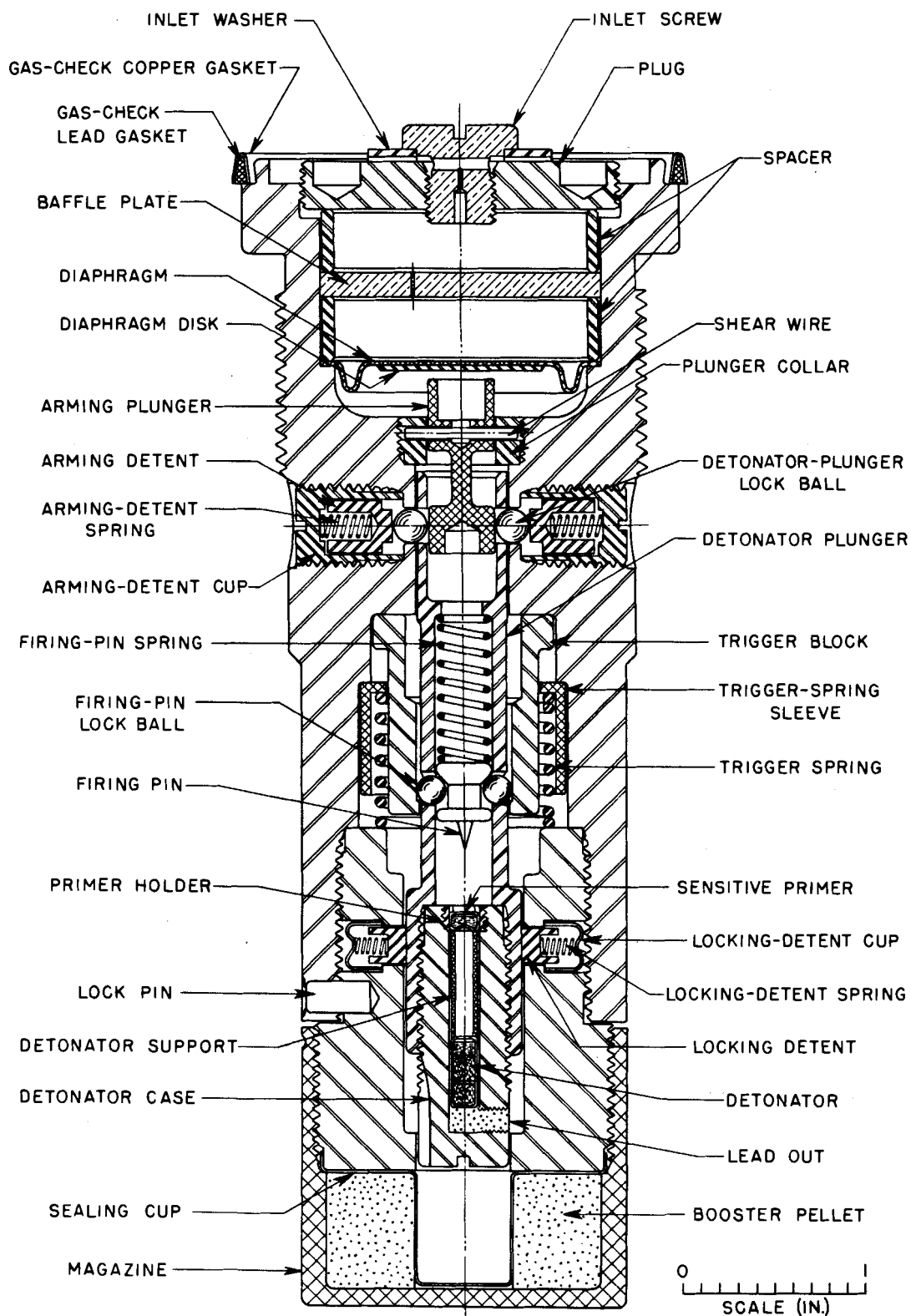


FIG. 85. DDR-2 fuze, unarmed.

The behavior of an armed DDR-1 or DDR-2 fuze on impact is much the same as that of the DDR-3 and DDR-4. The only important difference is that in the DDR-2 the trigger spring is always free, instead of being unlatched by the impact. This means that unless the initial impact is considerably greater than the deceleration at which the trigger spring is set the fuze will fire on impact rather than delay until the deceleration has dropped off to this value. For example, if a DDR-4 is fired into water in a rocket for which the initial deceleration is about 100 g, then the fuze will not fire until the rocket has traveled under water far enough for the deceleration to drop to about 75 g. If a DDR-2 with the same strength of trigger spring is fired under the same conditions, the fuze will fire immediately upon impact.

The fuze is partially detonator-safe. If the detonator is fired in the *unarmed* position, the tetryl booster pellet is well away from the direct blast from the lead-out in the detonator case and is presumably protected from hot gas by the thin copper "hat" which closes the main cavity in the fuze body. However, if the lead-out is made large enough to initiate the booster (when it is fired in the *armed* position), it shatters the detonator case. If, then, the detonator is fired in the *safe* position, the fragments of the shattered detonator case may punch holes in the hat and allow the hot gas to reach the booster, occasionally causing it to ignite.

5.052. ADVANTAGES OF THE DDR-2 FUZE.—The DDR-2 fuze has some advantages over the DDR-3, chief of which is that the DDR-2 fuze body just forward of the external thread is much stronger. There is therefore less chance of the fuze being crushed sufficiently, by ricochets from heavy plate, to prevent its firing (see 5.026). The DDR-2 is also a little simpler in design, and there is less interdependence of the various critical dimensions.

5.053. PERFORMANCE.—Tests have shown that the DDR-1 and DDR-2 fuzes perform quite satisfactorily. Preliminary tests indicated that the setback lock will operate properly if the springs behind the lock balls are of the proper strength. The fuze could probably be made satisfactory for use from land-based aircraft by the following changes:

1. Redesigning the explosive chain to make the fuze detonator-safe.
2. Providing better support for the detonator plunger by increasing the size of the lock balls. This would involve increasing the detonator plunger diameter and the diameter of the external thread on the fuze body (from 2.0-in.-12 to 2.125-in.-12 thread as in the DDR-4).
3. Modifying the detonator plunger so that the larger firing spring from the DDR-4A could be used.
4. Strengthening the shoulder that stops the detonator plunger on impact by making it at least 50 per cent thicker.

Chapter 6

FUZES FOR SPIN-STABILIZED ROCKETS

6.00. INTRODUCTION.—The basic data for the important spin-stabilized rockets are collected in Table 1, and as can be seen the only significant difference in properties from the fin-stabilized rockets is the spin itself, which ranges from 4000 to 18,500 rev/min.

Since the spin is produced by the tangential component of the reaction of the gas escaping from the motor through the canted nozzles, the spin acceleration and velocity during burning vary directly with the forward acceleration and velocity; the axial acceleration being roughly constant during the whole burning time, the spin acceleration is likewise constant. From the standpoint of fuze design the spin

TABLE 1. Characteristics of spin-stabilized rockets, based on field data.*

DESIGNATION OF ROCKET CIT MODEL NO.			3.5"/4	5.0"/1	5.0"/2	5.0"/5	5.0"/10	5.0"/14	5.0"/9	5.0"/3
			GPSR 24	HCSR 50D	HCSR 51A	HCSR 34	GPSR 20	GPSR 39A	CnSR 32	PySR 40
INITIAL PRESSURE (lb/in. ²)	AT	0°F	1175	1500	1370	1300	1050	1030	1170	1300
		70°F	1830	2030	2020	1850	1770	1590	1700	1720
		120°F	2150	2620	2570	2370	2370	2075	2500	2375
ACCELERATION (g)	AT	0°F	30.0	12.1	15.6	22.5	32.0	46.6†	34.1	—
		70°F	46.0	17.2	22.9	30.5	53.2	50.0	50.5	32.3
		120°F	53.2	22.8	30.0	41.2	71.5	65.2	71.5	—
BURNING TIME (sec)	AT	0°F	0.86	1.17	1.22	1.20	1.53‡	1.09†	1.53‡	1.20
		70°F	0.60	0.84	0.90	0.94	1.04‡	0.86	1.04‡	0.94
		120°F	0.47	0.66	0.71	0.77	0.75‡	0.62	0.75‡	0.77
BURNING DISTANCE (ft)	AT	0°F	290	220	300	440	1025	674†	975	500
		70°F	230	165	250	385	765	589	750	466
		120°F	210	140	200	350	550	440	585	399
VELOCITY (ft/sec)	AT	0°F	725	400	520	770	1440	1318†	1370	740
		70°F	750	415	530	780	1510	1322	1480	757
		120°F	765	415	530	800	1460	1380	1450	753
SPIN (rev/min)	AT	0°F	—	4570	5100	—	—	—	—	—
		70°F	12240	4030	5040	8160	15000	18540	14760	6900
		120°F	—	4020	5100	—	14280	—	—	—
CREEP FORCE (g)	AT	70°F	0.51	0.12	0.20	0.43	2.83	1.09	4.36	0.42
QE FOR RANGE DATA			30°	45°	45°	45°	11°	5°	8°	45°
RANGE (yd)	AT	0°F	3700	1450	2300	4700	4600	—	2650	—
		70°F	4000	1500	2350	4950	5100	2250	3050	4474
		120°F	4200	1550	2420	5150	5250	—	3300	—

* Mean values for experimental firings; not necessarily valid for standard production.

† At 40°F.

‡ Static reaction time; no field data available.

makes available, in addition to the forces available in fin-stabilized rockets, both angular acceleration (resulting in angular setback forces) and centrifugal force. Although the spin acceleration offers several interesting possibilities, it has not been utilized in any fuze to date, and since it is a relatively small force it can usually be ignored. The only place where it was found to play any part in present fuzes was in the CTSR fuze (see 6.043).

On the other hand the centrifugal force is large and usable. Nearly all standard projectile fuzes are spin-arming, and those which do not also utilize the very large gun-setback forces can be armed in rockets; consequently, most efforts were directed towards the use of such fuzes, either directly or with slight modifications.

The most important quantity that arises in these cases is the arming distance, the particular distance traveled during burning at which the rocket spin velocity becomes sufficient to complete the arming of the fuze. This distance is reasonably constant, and can be accurately determined for any particular kind of rocket. By assuming that the acceleration is constant during the course of burning it will be seen that $s = (w/w_b)^2 t_b v_b / 2$ or $s = (w/w_b)^2 s_b$, where s is the distance, in feet, at which the spin velocity reaches the value w , and w_b , s_b , t_b , and v_b are respectively the spin velocity, distance (in feet), time (in sec), and velocity (in ft/sec) at the end of burning. Of course, w and w_b must be in the same units. Actually the acceleration is not constant during the last third of the burning, but the error which results is not important except for refined calculations.

As a typical illustration, the point-detonating Nose Fuze Mk 30 and the Mk 44 auxiliary detonating fuze are used in several different rocket types, and Tables 2 and 3 show the calculated arming distances for these fuzes in the different rockets; the minimum arming spin for the Mk 30 is 1500 rev/min and for the Mk 44 is 3000 rev/min.

TABLE 2. Calculated minimum arming distances (ft) for Mk 30 fuzes in various rockets.

ROCKET DESIGNATION	5.0"/1 HCSR	5.0"/2 HCSR	5.0"/5 HCSR	5.0"/14 GPSR
CIT MODEL NO.	50D	51A	34	39A*
BURNT SPIN AT 70°F (rev/min)	4030	5040	8160	18,540
ARMING DISTANCE AT 0°F (ft)	24	26	—	—
70°F	23	22	13	4
120°F	19	17	—	—

* No fuzing has been established for this rocket, but it is included here to show how short the arming distance would be if the Mk 29 fuze (which arms at the same spin as the Mk 30) were used without modification.

As can be seen, the arming distances of these and many other projectile fuzes are relatively short, and of course could be made substantially larger simply by using stronger detent springs, which would require higher spin for arming. Since the few measurements that have been made indicate that the spin may fall off by as much as 25 per cent at full range, the fuzes must remain armed at 75 per cent of the full burnt spin. Consequently, if the arming process is "reversible" (that is, if

TABLE 3. Calculated minimum arming distances for Mk 44 fuzes (various mods) in various rockets.

ROCKET DESIGNATION CIT MODEL NO.	5.0"/2 HCSR 51A	5.0"/5 HCSR 34	5.0"/10 GPSR 20	5.0"/14 GPSR 39A*	3.5"/4 GPSR 24
BURNT SPIN AT 70°F (rev/min)	5040	8160	15,000	18,540	12,240
ARMING DISTANCE AT 0°F (ft)	104	—	—	—	—
70°F	89	52	31	15	14
120°F	72	—	—	—	—

* No fuzing has been established for this rocket, but it is included here since some form of the Mk 44 auxiliary detonating fuze might be utilized.

the fuze can become unarmed again when the spin velocity decreases below the arming spin velocity) the fuze must arm at 70 to 75 per cent of the burnt spin, and this reduces the maximum possible arming distance to 50 per cent of the burning distance. There are several ways to avoid this difficulty: in some fuzes a special mechanism keeps the fuze locked in the *armed* position (as in the delay assembly in the Mk 100 fuze), and in another case (as in the Mk 44 auxiliary detonating fuzes) the arming mechanism is essentially a one-way system, so that once the fuze has been armed the detent springs are completely disengaged so they cannot reararm the fuze, and in addition the force resulting from spin deceleration itself opposes any reversal of the arming process. Under these conditions consistent arming at 90 to 95 per cent of the burnt spin (80 to 90 per cent of the burning distance) should be perfectly feasible.

In the case of fuzes in which arming is reversible, such as the Mk 31 and 36, and the interrupter in the Mk 29, Mk 30, and Mk 100, a number of considerations should be mentioned. Thus it is possible, through appropriate design, to have high initial arming spin values and yet keep the fuze armed even though the spin again falls below the initial value, by making the typical spring-detent mechanism "unbalanced." Since centrifugal force increases with distance from the spin axis, a detent that has moved out at any spin velocity is exerting considerably more force than before, and if the spring opposing this movement is appropriately chosen there will be no resultant restoring force at this particular spin velocity; in fact the detent will be held out by centrifugal force until the spin velocity drops to a new value lower than that which caused it to move out. The extent to which this sort of unbalance can be attained depends on a number of factors, which will be discussed in some detail, since the unbalance permits getting the maximum arming distances with a minimum of design change in the standard gun projectile fuzes of this type.

Taking the general case for an arming mechanism in which centrifugal force causes a detent to move outward perpendicular to the spin axis and compress a spring, we can let $R = w_1/w_2$, where w_1 and w_2 are the spin velocity with the fuze unarmed (detent in) and armed (detent out), respectively. The centrifugal force is balanced at all times by the detent spring, and the rate constant T of the spring can be shown to be related to the fuze design data by the relations

$$\frac{s_1}{s_2} = \frac{mcw_2^2 - T}{mcw_2^2 R^2 - T} = \frac{mcw_1^2/R^2 - T}{mcw_1^2 - T} \quad \text{when } R \neq 1 \quad (1)$$

$$T = mcw_2^2 = mcw_1^2 \quad \text{when } R = 1 \quad (2)$$

In these equations s_1 and s_2 are the distances from the spin axis to the center of mass of the detent in the unarmed and armed states, respectively, m is the mass of the detent, and c is a constant whose value depends on the units. (If s is in inches, w in thousands of rev/min, m in grams, and T in lb/in., $c = 0.0625$.)

When $R = 1$ the spring tension is such that the spring exactly balances the detent for its entire motion at the particular spin. In most projectile fuzes $R < 1$, which means that as the spin velocity slowly builds up during burning the detent gradually moves out and is out at the distance s_2 only when the spin velocity has reached w_2 . Whenever the spin velocity drops again to w_2 the detent begins to move back in and the fuze is no longer armed. In the Mk 31 fuze, for example, $R = 0.885$, and since it requires about 400 more revolutions per minute to carry the detents all the way out after they have started out, this extra spin is included in the extremely liberal arming tolerances for the fuze (3000 to 4500). Much more uniform arming could be attained with commercial springs simply by decreasing the spring rate, and limits of 4000 to 4500 could be maintained. For gun projectiles this is perhaps unimportant, but in rocket fuzes, where there is some interest in getting as long an arming distance as possible, it is more significant, since the actual minimum arming distance would be increased.

To make the arming unbalanced it is necessary that $R > 1$. This is a desirable condition for all rocket fuzes in which accurate time of arming is desired, since the force pushing the detent out is a maximum, tending to carry it out rapidly, and stray frictional forces are not important. The detents and springs of both the CCISR and CTSR fuzes (see 6.042 and 6.043) were designed on this basis.

Since $w_1 = R w_2$, the greatest holdup of the unarming process resulting from unbalance will be when R is a maximum. However, when $R^2 > s_2/s_1$ the spring rate T becomes negative (when $R^2 = s_2/s_1$, $T = 0$). Actually spring washers of the Belleville type can be made which have a zero or negative rate, and an interesting problem would be to work out the design for using them in an application such as this. A stack of many small washers (similar to the stack of small conical springs used as the firing-pin spring in the DDR fuze, 5.026) might be very suitable and simple, and would offer considerable advantage.

However, if the design is limited to typical helical compression springs, which have a positive rate, we must then impose the restriction, for unbalance, that $s_2/s_1 \geq R^2 \geq 1$. It should be borne in mind, of course, that R is directly related to the spring rate, and in fact the greatest possible value of R^2 is s_2/s_1 , which occurs when $T = 0$, that is, when the spring has a zero rate, so that the "limit" is never attainable under actual conditions. However, the limiting condition is a useful relation, since it gives the ultimate limit of possible unbalance. Thus, in the Mk 31 (and Mk 36) fuze $s_2/s_1 = 1.32$, so that the maximum possible $R = 1.15$. This is not attainable with a helical coil spring, but a few calculations of real springs indicate that a maximum R of 1.08 is possible, so that we may expect to be able to hold

the fuze armed to a spin some 8 per cent lower than the arming spin. This may not appear to be much, but it probably represents more than the normal variations in manufacturing tolerance that would occur, and on this basis we can say that it would be possible to make the fuze arm at 4000 to 4500 rev/min (instead of the present 3000 to 4500) and stay armed down to spins as low as 4300. A further use of this relation is that it clearly indicates that considerable advantage is gained by simply keeping the ratio of s_2/s_1 as large as possible. In general it would appear desirable to attain this by making s_2 larger rather than by decreasing s_1 , since for detents close to the axis only slight off-center spin may cause trouble. In the Mk 31 fuze, for example, if the detent were lightened considerably, s_2 , which now is about 0.455 in., might be increased to 0.505 in. This would give a maximum R of 1.21, and perhaps 12 per cent lower than arming spin would be attainable with a real spring.

From the relation between R and T it is clear that the minimum spring rate is necessary to get the maximum value of R . In view of the restricted space usually involved, it will be found much easier to get a low spring rate with lighter loads, and consequently the detents should be as light as possible, especially when high spin rates are involved.

Another way to make the unbalance greater is to have a detent which extends partly across the spin axis, so that its effective mass becomes greater as the detent moves out, exerting considerably more force. In this case the relation between R and T should be modified so that

$$\frac{s_1}{s_2} = \frac{m_2 c \omega^2 - T}{m_1 c \omega^2 R - T} \quad (3)$$

where m_1 and m_2 are the effective masses of the detents in the *unarmed* and *armed* positions, respectively, and the maximum R^2 is not s_2/s_1 but $m_2 s_2 / m_1 s_1$. The ultimate maximum R for the Mk 29 (or Mk 30) fuze then would be about 2.2, and with a real spring and a somewhat lighter interrupter it might be possible to get as high as 1.5 or more. On this basis the Mk 29 or Mk 30 fuze could be made to arm at the very maximum spin rate and remain armed even for a 50 per cent decrease in spin simply by appropriate design of the interrupter spring; this would probably entail making the interrupter itself lighter, to permit the necessary lower spring rate.

There is a slight round-to-round variation of the burnt spin, but this is usually unimportant and is less than the manufacturing tolerances of the springs normally used in the fuze arming mechanisms. Table 4 gives an indication of the order of magnitude of the effect for the one kind of rocket on which a number of spin measurements were made, and the per cent deviations, which may be representative of all rockets. The calculations are based on the simplified treatment indicated above.

So far no precise picture of down-range rocket behavior is available, but the tendency of rockets to develop nutations, and the forces resulting from such behavior, may be of importance in fuze work. The rocket has a certain amount of yaw with respect to the path of the trajectory, and the nutation is simply a result

of the changing orientation of this angle with respect to the path. Insofar as a fuze is concerned the force apparently is small, and may be represented by a vector which rotates with respect to the rocket at a rate of ω/γ , where γ is the ratio of the transverse to the axial moment of inertia (roughly 20 for most rockets) and ω is the spin velocity. The net effect on any fuze is to superimpose on the centrifugal force an additional small force whose direction varies through all orientations at a rate of 0.05 revolution for each revolution of the rocket. In the case of nose fuzes the net effect may be somewhat larger than that from the similar behavior in projectiles, since the center of gravity of rockets is considerably farther from the nose. The effect was believed to be important in the behavior of the Mk 52 auxiliary detonating fuze (see 6.024) and in the CTSR fuze (see 6.043).

6.01. BASE FUZES.—Only one base-fuzed spinner rocket, the 5.0-in./9 CnSR was ever developed at CIT; originally this utilized the Mk 36 fuze, which had a 0.01-sec delay, but it was replaced almost at once by the Mk 31 fuze, which is identical except that it has no delay; both of these are standard projectile base fuzes and were used without modification.

6.011. MK 31 AND MK 36 FUZES.—For a complete detailed description of these fuzes and their behavior in projectiles, see U. S. Navy OP 1212. The fuzes have a central plunger carried on ball bearings containing the detonator and lead-outs which, in the *unarmed* position, are out of line with the lead-ins and boosters in the fuze body itself. The plunger is held in this position by four centrifugal detents which move out at 3000 to 4500 rev/min, after which the plunger is held only by an anticreep spring. On impact the plunger moves forward, carrying the sensitive stab-type primer against the sensitive firing pin. This primer initiates a percussion primer which, in the Mk 31 fuze, flashes directly to a compound detonator in the plunger and then to the lead-outs, lead-ins, and boosters. In the Mk 36 fuze a 0.01-sec black powder delay pellet is interposed between the percussion primer and the compound detonator. When used in gun projectiles the sensitive firing pin, which is slightly movable with respect to the fuze body, moves down under the influence of the gun setback forces and binds one pair of the centrifugal detents until the acceleration stops, providing a "bore-safe" feature. This does not happen with the low acceleration of rockets.

The minimum arming distance for these fuzes in the 5.0-in./9 CnSR, calculated for the minimum arming spin of 3000 rev/min, is 31 ft.

An extensive series of tests were made with essentially the standardized rockets, using these fuzes in the 5.0-in. Mk 8-0 head to determine the limiting behavior of the fuze and the head.¹ In brief, it was found that the rockets ricocheted at angles of impact of about 8° on dirt, but did not ricochet at angles of 5° on water; the fuzes functioned satisfactorily in all cases.

In the plate tests it was found that the fuzes functioned on 85 per cent of the hits on 1/8-in. mild steel plate at obliquities of up to 55°; the Mk 31 fuze gave detonations 3 to 8 ft behind the plate, and the Mk 36 fuze 9 to 24 ft, with the

¹ *Behavior of the 5.0-in. HVSR Common Prototypes*, (dirt impact and water impact), CIT Fuze Group, CIT/PMC 2.57, 5 November 1944, Part 1, pp. 13-14; *Behavior of 5.0-in./10 CnSR Models 32 and 32A on Plate*, J. B. Hatcher, CIT/PMC 2.80, 29 April 1945, Part 1, pp. 4-8.

TABLE 4. Spin variation for 60 rounds of 5.0-in./2 HCSR

ROUND NO.	OBS'D BURNT SPIN VELOCITY	OBS'D BURNING DISTANCE	CALC. FLIGHT DISTANCE FOR 3000 REV/MIN	CALC. TIME FOR 3000 REV/MIN
	(rev/min)	(ft)	(ft)	(sec)
1	5376	265	82.4	0.57
2	5226	286	94.1	.61
3	5022	330	117.5	.75
4	5142	258	87.7	.56
5	5112	274	94.5	.60
6	5208	274	91.0	.57
7	5016	264	94.2	.60
8	4800	261	102.0	.61
9	5178	257	86.1	.56
10	4980	256	92.7	.58
11	5166	259	87.5	.56
12	5478	285	85.5	.58
13	5268	262	84.9	.56
14	5052	261	92.1	.58
15	5172	258	86.7	.57
16	5190	268	89.5	.58
17	5166	270	91.3	.59
18	5514	308	91.2	.60
19	5112	276	95.2	.61
20	5244	259	84.7	.55
21	5190	280	93.5	.61
22	5388	283	87.7	.59
23	5010	268	96.2	.60
24	5046	259	91.7	.56
25	5142	267	90.8	.59
26	5028	251	89.4	.56
27	4878	243	91.9	.57
28	—	264	—	—
29	5052	254	89.7	.58
30	5016	238	85.2	.53
31	—	259	—	—
32	5376	256	79.6	.52
33	5166	255	86.2	.57
34	5082	259	90.1	.56
35	5076	275	96.0	.61
36	5046	254	89.9	.57
37	5256	348	113.4	.76
38	5106	270	93.4	.59
39	—	245	—	—
40	5184	283	94.8	.60
41	—	199	—	—
42	—	221	—	—
43	4986	286	103.5	.64
44	—	282	—	—
45	5088	265	92.2	.60
46	5040	287	101.6	.63
47	5148	266	90.4	.58
48	—	281	—	—

TABLE 4. Spin variation for 60 rounds of 5.0-in./2 HCSR

ROUND NO.	OBS'D BURNT SPIN VELOCITY (rev/min)	OBS'D BURNING DISTANCE (ft)	CALC. FLIGHT DISTANCE FOR 3000 REV/MIN (ft)	CALC. TIME FOR 3000 REV/MIN (sec)
49	5244	250	81.8	0.52
50	5094	251	87.1	.54
51	5184	267	89.4	.57
52	5112	264	91.1	.58
53	5178	276	92.5	.58
54	5094	269	93.3	.58
55	5046	266	94.2	.58
56	4932	270	99.9	.61
57	5244	293	95.8	.61
58	5070	268	93.8	.59
59	5256	272	88.7	.58
60	5100	189	65.4	.41
AVERAGE	5137	266	91.5	0.58
MEAN DEVIATION	±102	±15	±5.0	±.03
PER CENT MEAN DEVIATION	±2.0	±5.6	±5.5	±5.2

limits representing the behavior at short and full-range impact velocities. (These fuzes do not function on less than $\frac{3}{8}$ in. of mild steel plate in gun projectiles.) The limit for clean penetration with high-order detonation behind the plate for the Mk 36 fuze in the Mk 8-0 head was 1 in. of STS at 30° obliquity; the Mk 31 fuze gave good performance on 1-in. STS at 45° obliquity. In both cases the failures were found to have been due to head breakup—the fuzes had functioned high order. Since the 5.0-in./9 CnSR is capable of punching a button from 1½-in. STS, even with head deformation, it is clear that a better head than the Mk 8-0 is justified and highly desirable for this rocket.

6.02. AUXILIARY DETONATING FUZES (BOOSTERS).—No standard projectile nose fuze carries any substantial explosive charge capable of directly initiating the detonation of the projectile, and the practice is to utilize a separate component which serves to carry the explosive train from the nose fuze to a sizable pellet of tetryl. This component, which is called an “auxiliary detonating fuze” (commonly shortened to “aux det”) by the Navy and a “booster” by the Army, varies from the complex mechanism of the Navy Mk 54 aux det to the simple Army M22 booster, which is nothing but a detonator embedded in a pellet of tetryl. The Army boosters are normally attached to fuzes; the Navy auxiliary detonating fuzes are normally in the high-explosive head. With the policy of utilizing standard projectile fuzes for rockets, it became necessary also to utilize components of this type. The only Army booster considered was the M21A1 booster, which is a part of the Army M51A2 fuze. This booster was used in the T-28 fuze until it was found to be unsafe.¹

¹ For a discussion of this booster see the T-28 fuze, Section 6.033.

6.021. THE MK 17 SERIES OF AUX DETS.—There are a number of standard Navy auxiliary detonating fuzes in the series which begins with the Mk 17; this fuze was modified several times with minor changes and for various projectiles and spins, to become the Mk 35, 43, 46, 54, and 55, all of which are fully discussed in the Navy OP 1212. None of these was used in rockets except in occasional experimental tests, but it is interesting to note that in one test the Mk 46 and Mk 17-8, which arm at spins of 3000 to 4500 and 3000 to 4000 rev/min respectively, did not arm consistently in the 5.0-in. HCSR, which has a minimum burnt spin of 8000 rev/min. This was considered to be due to off-center spin; the detents and rotor of these fuzes are quite close to the geometrical axis, and only a slight displacement would be needed to prevent arming, especially of the rotor.

6.022. MK 44-1 AUXILIARY DETONATING FUZE.—This fuze is completely described in the Navy OP 1212; it consists simply of two off-center rotors, carrying a detonator and lead-in respectively, which are locked by spring-held detents. Below this mechanism are a lead-out and the tetryl booster pellet. The fuze is normally screwed into a fuze-liner ring, which is inserted directly into a cavity in the explosive charge in the rocket head at the loading plant.

The fuze arms at spins of 3000 to 4500 rev/min, and the calculated minimum arming distances of this or the Mk 44-2 fuze in the rockets in which they are used are to be found in Table 2, p. 183. When this fuze was first adopted it gave very satisfactory performance with various nose fuzes, including the Mk 30; later there began to occur a high percentage of failures, which have not been satisfactorily explained. It was learned only shortly before rocket work at CIT terminated that this fuze is not acceptance-tested for functioning with the Mk 30, so it is quite possible that the peculiar satisfactory behavior of the early lot and failure of nearly all later lots of Mk 44's used were due to some changes in the fuze which would not appear in routine testing. The problem of this failure was turned over to the Naval Ordnance Test Station, and considerable progress toward a more satisfactory design was made there.¹

6.023. MK 44-2 AUXILIARY DETONATING FUZE.—This fuze was developed to provide an aux det that would function from the M48 type delay assemblies as in the M48A2 and Mk 100-0 nose fuzes. It is identical with the Mk 44-1 except that a 0.129-in.-diameter hole is drilled through the cover disk, and an additional sealing disk of 0.002-in.-thick copper is used to cover the hole and seal the fuze.

With the nose fuze set on *delay* about 15 per cent duds occurred in this application with the 3.5-in./4 GPSR when rounds dug in on dirt impacts, and numerous duds under various conditions were reported by the Navy with the 5.0-in./10 GPSR. While the failures, in the first case at least, were characterized by a sort of "low-order" behavior of the Mk 44 detonator, no changes in the Mk 44-2 seemed helpful or desirable, and eventually the nose fuze itself was modified either (1) to work with this aux det (see Mk 100-2, 6.036) or (2) to avoid the use

¹ Project 125 GF, Final Report. *Functioning of Auxiliary Detonating Fuze Mk 44 Mod 1. Influence of Cover Disk Design on Functioning Performance*, OCE 55, Research and Development Department, NOTS, Inyokern, 20 August 1945.

of this aux det entirely and use the Mk 44-1 instead (see Mk 100 Type A, 6.037).

6.024. MK 52 AUXILIARY DETONATING FUZE.—This fuze, which is completely described in the Navy OP 1212, is identical with the Mk 44-1 except for its lower arming spin of 1750 ± 250 rev/min. It was adopted for the 5.0-in./1 HCSR, which has a minimum spin of about 4000 rev/min; its calculated minimum arming distance in this rocket is 28 ft at 120°F.

In tests with the Mk 52 fuze in the early experimental 5.0-in./1 HCSR several duds occurred in which one of the rotors of the fuze was found unarmed. The recovered dud fuzes were found to arm perfectly, even when spun off-center, at spin velocities far below the burnt spin obtained in the rocket. Since any spin deceleration would tend to keep the fuze armed, the only explanation seemed to be that in some way the nutation forces were responsible. However, the final standardized rocket had a 10 per cent heavier propellant grain, with a resultant increase in spin, and it was probably more stable. Tests with this rocket were planned but were held up awaiting heads as the rocket project terminated.

6.03. NOSE FUZES.—The 3.5-in./4 GPSR, the first spin-stabilized rocket to be developed, was intended to have the general characteristics of the 75-mm pack howitzer. In this respect it was the first general-purpose rocket—one that might be utilized under a number of different tactical conditions. Clearly the rocket should have fuzing adequate to all situations, and in particular delay fuzing for penetration effects. In Navy practice delay fuzing of projectiles is always obtained with base fuzes, and it is of course true that only with a base fuze can the full limits of penetration with delay action be obtained. On the other hand all Army projectile nose fuzes have a delay assembly, so that the fuzes can be set either *superquick* or *delay* in the field. Such a nose delay fuze cannot be expected to give satisfactory behavior under all conditions, since either the fuze or the head itself may fail on some especially heavy targets. In the case of rockets, however, selective-delay nose fuzing offers the distinctive advantage of penetration on many targets, as well as cratering or air bursts from ricochets on ground impacts. This is possible simply by setting the fuze *delay* in the field, without the necessity of a separate fuze, head, or round; such nose delay fuzes will in nearly every case stand up to the full penetration of the rocket head.

In view of the general policy of adopting standard projectile components as much as possible, such a nose delay fuze was developed from combinations of the standard Army and Navy fuzes. As other spin-stabilized rockets were developed, further combinations became necessary, and although all of the fuzes will be discussed below, it may be well to summarize the basic similarities of the standard projectile nose fuzes themselves.

The Army M48 fuze was the original and basic projectile fuze from which all other point-detonating projectile nose fuzes available in 1945 had been derived. There have been several minor modifications of the M48 fuze by the Army, these being designated as M48A1, M48A2, etc.; in addition, the same fuze, when assembled to various boosters, has designations in the series M51, M51A1, M51A2, etc. The Navy had only two point-detonating nose fuzes, the Mk 29 and Mk 30, both with various mods. The Mk 30 was adapted from and is essentially identical

with the M48, except (1) that the metal ogive is replaced with a bakelite ogive, and (2) the inertia-firing delay assembly, which permits the M48 to be set for a delay burst, has been replaced with a bakelite block containing a simple relay detonator. This was necessary in order to provide sufficient power to initiate the Navy auxiliary detonating fuzes of the Mk 17 series. The Mk 29 fuze is identical with the Mk 30, except that a different ogive makes it slightly shorter and gives it a larger diameter.

6.031. MK 29 AND MK 30 FUZES.—These fuzes are completely identical, except for the shape as noted above, and are described in detail in the Navy OP 1212. They consist of a nose detonator assembly and a flash tube leading to the relay detonator. An interrupter is interposed across the flash channel in the *safe* position, and when the fuze is set to the ON position this may move out on centrifugal force to clear the flash channel and permit the flash from the nose detonator to initiate the relay detonator. The interrupter slides in an inclined hole, so that in guns the interrupter does not move out until the gun setback forces are over, providing a bore-safe feature. However, the setback of rockets is so small that it plays no part in the arming process, and the fuze arms as soon as the spin reaches the required value (1500 to 2000 rev/min). When the fuze is set OFF the interrupter is held in place across the flash channel, and the relay detonator is not supposed to function even if the nose detonator is accidentally fired. Actually in the Mk 29 and Mk 30 Mods 0, 1, and 2 the relay detonator fired in about 50 per cent of the cases; according to the Navy OP 1212, the Mod 3 fuzes, which have an additional 0.010-in. aluminum sheet above the relay detonator, this behavior occurs in less than 1 per cent of the fuzes.

The Mk 29 fuze was used originally for a short time in the 3.5-in./4 and the 5.0-in./10 GPSR, until it was replaced first by the selective-delay nose fuze T-28 and then almost immediately by the selective-delay nose fuze Mk 100 (in various mods).

The Mk 30 fuze is at present used in all models of the 5.0-in. HCSR, and its calculated arming distance for each of these rockets is shown in 6.00, Table 2. In general, the fuze behaves substantially the same as when used in gun projectiles; it functions on earth or water at ricochet angles as small as about 5°, but because of the lower velocity of some of the standard rockets it is less sensitive; thus in the 5.0-in./5 HCSR it does not function on 1/8-in. 24ST aluminum plate.

6.032. THE M51A2 FUZE.—The Army drawings showed that the M51A2 fuze (see Fig. 86) had been standardized; actually it had never been produced in that form. However, the fuze is simply an assembly of the M48A2 fuze with the M21A1 booster, both of which were available in quantity and seemed to offer possibilities for quick procurement. Because of this availability the M51A2 fuze itself was used in the 5.0-in./5 HCSR (with the CIT Model 21 head) in early experimental work, but never was adopted for service use. For the same reason, these components were likewise used in the T-28 fuze (see 6.033).

Considerable information had accumulated to indicate the desirability of utilizing a selective-delay nose fuze on the 5.0-in./5 HCSR, and a number of tests were made with the M51A2 fuze which furnished the evidence that the delay feature

would be effective on particular targets.¹ In brief, it was found that the heads of the high-capacity rocket failed to stand up against concrete and mild steel plate over $\frac{3}{8}$ in. thick when the fuzes were set *delay*, but on lighter plate and on log and dirt targets the delay feature permitted very effective penetration; on ground impacts the delay setting gave air bursts when the rounds ricocheted from low-angle hits, and fine big craters of fox-hole size when the rounds dug in. It is to be hoped that the Mk 30 will be replaced in the 5.0-in. HCSR with a suitable selective-delay fuze.

6.033. THE T-28 FUZE.—This fuze, developed as the original selective-delay nose fuze for the 3.5-in./4 and 5.0-in./10 GPSR (using the 3.5-in. CIT Model 13 and 5.0-in. CIT Model 23 head, respectively), is simply a combination of standard projectile components. It is identical with the M51A2 in mechanism, but since the heads of these particular rockets have a larger diameter (2.985 in.) at the nose of the ogive, it was necessary to modify the outside shape. This was done by replacing the flash tube and metal ogive of the M51A2 with the shorter flash tube and shorter and larger diameter bakelite ogive from the Navy Mk 29 fuze, as is shown in Fig. 89a.

The Army gave this fuze the designation T-28, and produced 2000 of them; these were used, together with similar experimentally modified fuzes, in the early tests which established the effectiveness of the delay feature for the 3.5-in./4 GPSR.² It was shown that with the fuze set *superquick* ground craters were 10 to 12 in. deep and 30 to 36 in. in diameter. With the fuze set *delay*, at low impact angles the rounds gave ricochet air bursts with good fragment patterns 20 to 30 ft wide on the ground beyond the ricochet mark. At high impact angles the rounds dug in and made craters 3 ft deep and 4 ft in diameter in hard ground. With the fuze set *delay* a round would penetrate about 8 ft of sandbags or 3 ft of logs with satisfactory detonation behind the target.

On mild steel plate targets with fuzes set *delay*, penetration of $\frac{1}{2}$ in. at 45° obliquity and $\frac{5}{8}$ in. at 15° obliquity was obtained, with air bursts beyond. The rockets ricochet off $\frac{1}{2}$ -in. mild steel at 60° obliquity. On concrete wall targets of rather poor concrete (1700-lb/in.² strength) and with the fuze set *delay* the following behavior was observed: 12-in.-thick wall at 0° obliquity, complete pene-

¹ *Behavior of M51A2 Fuze with Model 21 Head on Plate*, CIT Fuze Group, CIT/PMC 2.59, 19 November 1944, Part 1, pp. 7-8; *Behavior of 5.0-in. HCSR Model 21 Head with M51A2 Fuze on Concrete, Log, and Dirt Impact*, CIT Fuze Group, CIT/PMC 2.67, 14 January 1945, Part 1, pp. 11-14; *Fuzing of the 5.0-in. HCSR*, Confidential Bulletin, CIT/LMC 1.13, 15 December 1944, pp. 9-16.

² *Performance of M48A1 Fuze on Log Target*, J. B. Hatcher, CIT/PMC 2.36, 11 June 1944, Part 1, p. 10; *Behavior of M48-M21A1 Fuze-Booster Combination on Mild Steel Plate*, J. B. Hatcher, CIT/PMC 2.37, 18 June 1944, Part 1, p. 4; *Behavior of M48A2 Fuze in 3.5-in. SR Model 21 on Ground Impact*, J. B. Hatcher, CIT/PMC 2.38, 25 June 1944, Part 1, p. 1; *Behavior of T-28 Fuze (Concrete Target)*, J. B. Hatcher, CIT/PMC 2.46, 20 August 1944, Part 1, pp. 3-4; (this article was based on CIT/OIC 12.8, 8 August 1944, which shows photographs of the hits on concrete targets); *Behavior of T-28 Fuze (Sandbag Target)*, J. B. Hatcher, CIT/PMC 2.46, 20 August 1944, Part 1, p. 3; *Behavior of the 3.5-in. SR Model 21 on Plate*, CIT Fuze Group, CIT/PMC 2.89, 15 September 1945, Part 1 pp. 3-4.

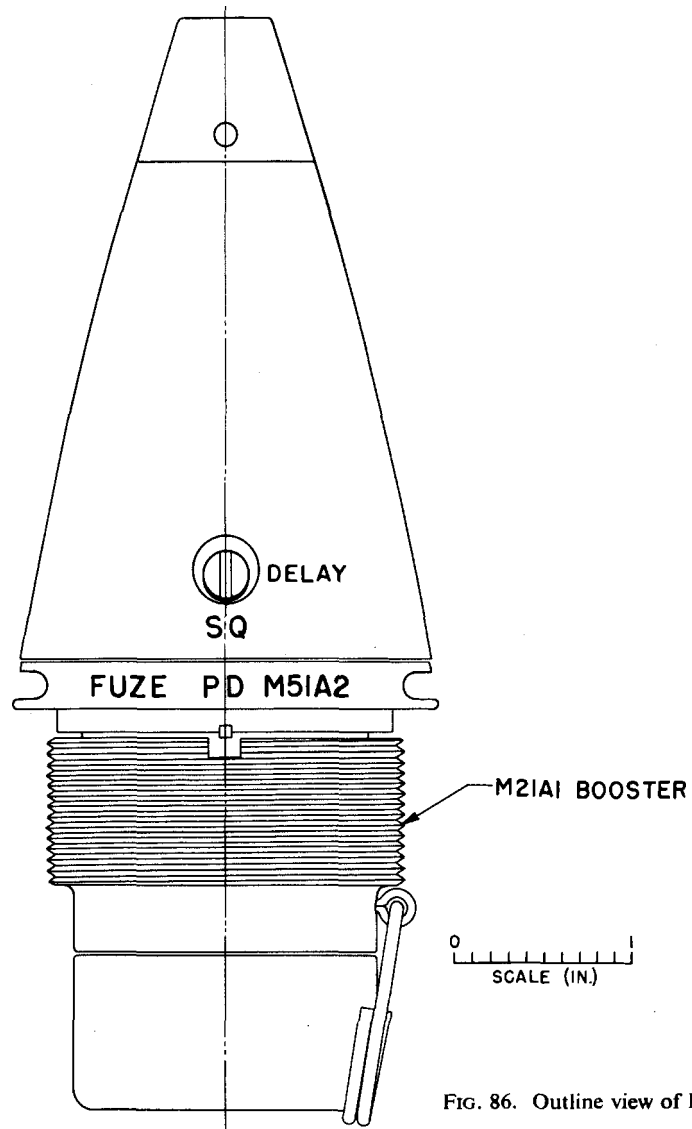


FIG. 86. Outline view of M51A2 fuze.

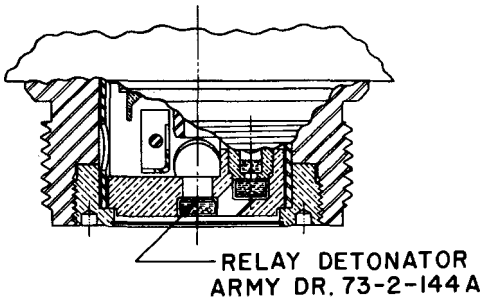


FIG. 87. Relay detonator used with Mk 100 Mod 2 fuze.

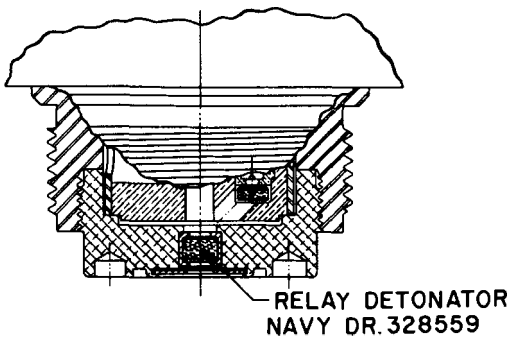


FIG. 88. Relay detonator used with Mk 100 Type A fuze.

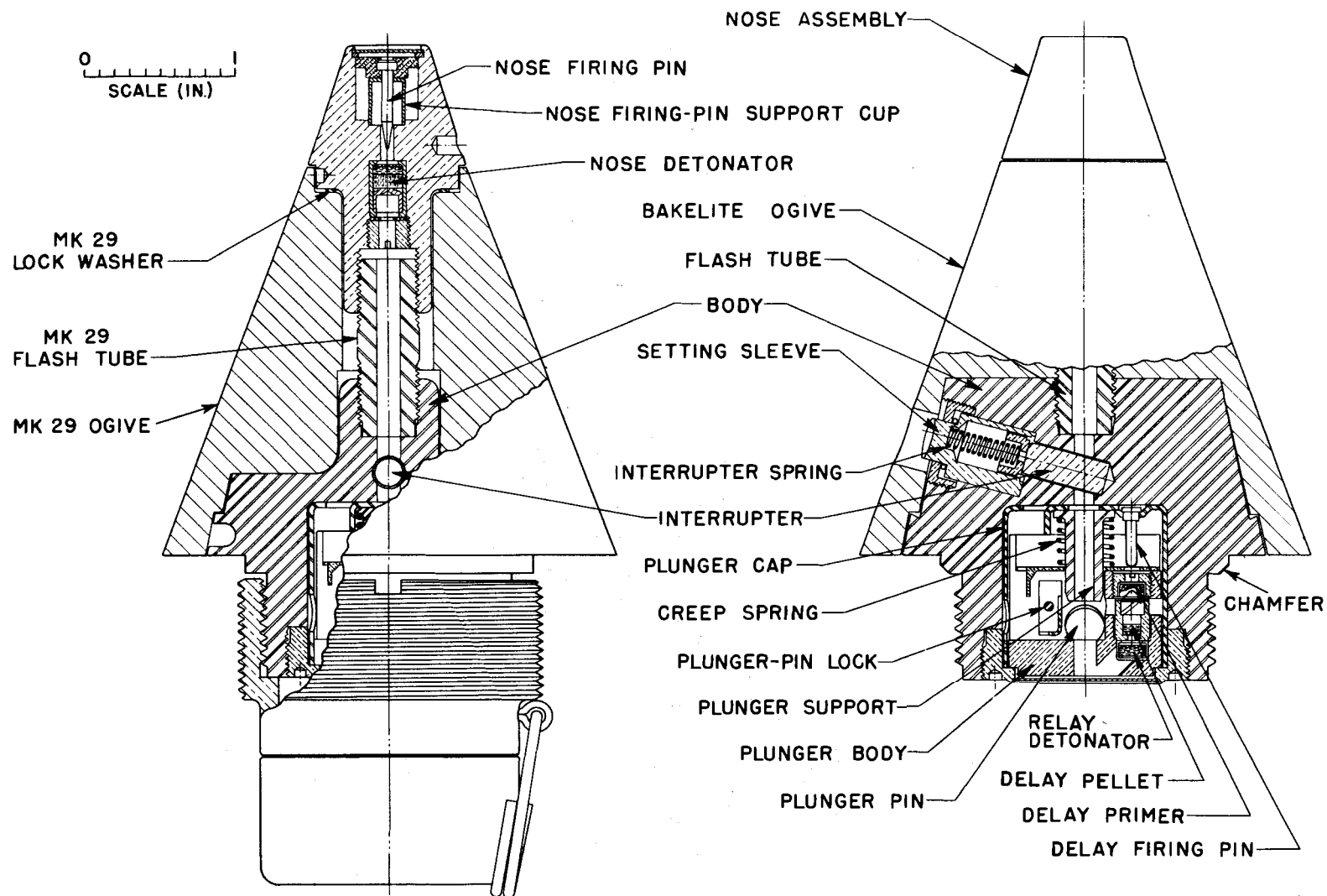


FIG. 89a. T-28 fuze, unarmed. All parts except as noted are identical with the M51A2 fuze.

FIG. 89b. Mk 100 Mod 0 fuze, unarmed. All parts are identical with the T-28 fuze except for body chamfer. Mod 0 has 0.05-sec delay; Mod 1 has 0.025-sec delay. View turned 90° from Fig. 89a.

tration with air burst behind; 24-in.-thick wall at 9° obliquity, detonation in the wall with back and front craters of 36 to 48 in.; 36-in.-thick wall at 15° obliquity, detonation in wall with 36 to 48-in. front crater with slight spalling of rear face.

When it was discovered that the M21A1 booster would arm on an appropriate blow or drop, once the safety pin was removed¹ the Mk 44-2 auxiliary detonating fuze (see 6.023) was developed in an attempt to replace the M21A1 booster. The nose fuze portion of the T-28 was retained and designated as the Mk 100-0 fuze by the Navy (see 6.034). The operation and behavior of the nose fuze portion of the T-28 are discussed below in connection with the Mk 100, but some remarks about the M21A1 booster may be appropriate here.

The Army M21A1 booster, which consists of a detonator held off center in an unbalanced rotor, simply screws onto the bottom 1.700-in. threads of the nose fuze. The rotor is held in the *unarmed* position both by a safety cotter pin, which must be removed when the fuze is screwed into the projectile or rocket head, and by a small spring-held detent. When the appropriate spin (1500 to 2000 rev/min) is reached centrifugal force moves the detent out and swings the rotor around into the *armed* position; the detonator in the rotor, being now in the center of the fuze, carries the flash from either the nose detonator or delay assembly of the M48A2 to the lead-in and booster beneath. Unfortunately the locations of the centrifugal pin and the off-center mass of the rotor are such that a side blow which can drive the centrifugal detent out will also drive the rotor against its stop pin; the rotor can then rebound off the stop pin before the detent moves back in place, and thus the booster becomes armed.

6.034. THE MK 100 MOD 0 FUZE.—As indicated above, the nose portion of the T-28 was retained as the Mk 100-0; and it should be noted that, while in Army terminology this fuze is the M48A2 (or the M51A2 without booster), when the flash tube and ogive are replaced with the Navy Mk 29 flash tube and ogive it can also be correctly identified in Navy terminology as a Mk 29 fuze with the relay assembly replaced by the Army M48A2 (or M51A2) delay assembly. Except for the shoulder above the 1.700-in. threads at the bottom of the body, all other portions of these fuzes are identical in both Army and Navy procurement; the fact that the shoulder on the Army body is not chamfered (see Figs. 86 and 89a) as is the Navy body (see Fig. 89b) makes it impossible to screw the Army body all the way into standard Navy projectile fuze liner rings. To permit either body to be used all recent CIT rocket heads have fuze liner rings (or fuze adapters as they are sometimes called) with either a very wide chamfer or, instead, a counterbore that will clear the Army shoulder.

As seen in Fig. 89b the fuze has the standard Mk 29 (or Mk 30 or M48) nose assembly, which consists simply of a brass nose piece housing a detonator directly beneath a firing pin supported on a light cup. This assembly screws onto a flash tube which is also screwed into the steel body, and the cloth-impregnated plastic ogive is thus held between the nose and the body.

The body contains the interrupter, which is simply a cylindrical slug that

¹ Study of Prematures in M48 and M51 Fuzes, L. Zernow, Aberdeen Proving Ground Research Laboratory Report, No. 452, 24 February 1944.

slides in a crosshole slightly inclined to the axis of the fuze. In the *unarmed* position the interrupter is held in the bottom of this hole, where it is supposed to block the flash channel completely, by the interrupter spring, which is in turn held in by the setting sleeve.

The body also holds the delay assembly. The explosive train of the delay consists of the primer, a 0.05-sec delay pellet, and a relay detonator, all of which are near the outside of the plunger body, and beneath a firing pin in the plunger cap. In the unarmed condition the firing pin is held from the primer by the creep spring and plunger support, which cannot move downward (or rather prevents the plunger from moving upward) because of the two centrifugal detents (plunger pins) in the plunger body.

When the rocket is fired centrifugal force drives the two plunger pins outward against their springs at a spin of 1500 to 2000 rev/min, and the delay assembly is armed; the pins are locked in the *armed* position by the plunger-pin lock, which swings outward and forward and interposes its inner tip between them. On deceleration from sufficient impact the plunger moves forward against the creep spring and carries the primer against the firing pin, initiating the delay train; the flash from the relay detonator initiates the aux det, which is assembled just below it in the round.

If the fuze has been set on *delay* the setting sleeve has been turned so that the interrupter is locked against any movement, and it then blocks the flash channel so that the fuze can function only as indicated. However, if the setting sleeve has been turned so that the fuze is set for superquick functioning, the sleeve does not lock the interrupter. In this case the interrupter may move outward under centrifugal force and compress the interrupter spring, clearing the flash channel at spins of 1500 to 2000 rev/min, so that the fuze is completely armed. On appropriate impact the nose firing pin crushes its supporting sleeve or cup and drives into the nose detonator. The flash from this detonator passes down the flash tube, through the center of the delay assembly, and fires the aux det.

It should be noted that both nose detonator and delay assembly function on proper impact. When the fuze is set *delay* only the delay assembly can initiate detonation, but when set *superquick* either may do so. With the *superquick* setting, so long as the nose detonator functions properly, the rocket will detonate before the delay pellet has burned through, but in the event of failure of the nose (as a result of faulty detonator, or a glancing or ricochet impact that is insufficient to fire the nose) the delay will still detonate the round.

If used in gun projectiles the fuze should be bore-safe; the slope of the interrupter hole is such that regardless of the spin the interrupter is held in the *unarmed* position, and as a result of the gun setback forces the delay plunger support will move down into slight shoulders on the plunger pins and lock them in the *unarmed* position, and the plunger lock cannot move out until gun setback is over. Of course, none of these things happens when the fuze is used in rockets.

This fuze was standardized for the 3.5-in./4 and 5.0-in./10 GPSR, with the Mk 44-2 aux det. The calculated minimum arming distances in these two rockets are 3.5 ft and 7.6 ft, respectively. When this fuzing was tested in the 3.5-in./4 GPSR, about 15 per cent duds occurred among the rounds with *delay* setting

when those rounds dug in on dirt impacts. The duds resulted from failure of the detonator in the Mk 44-2 to function properly, probably because of the small size of the Mk 44-2 detonator and lack of effective confinement when used with this nose fuze. There did not seem to be any simple way of modifying the Mk 44-2, and consequently attention was directed to the modification of the Mk 100 itself (see 6.036 and 6.037).

6.035. THE Mk 100 MOD 1 FUZE.—This fuze is identical with the Mk 100 Mod 0 in every respect, except that it has a 0.25-sec delay.

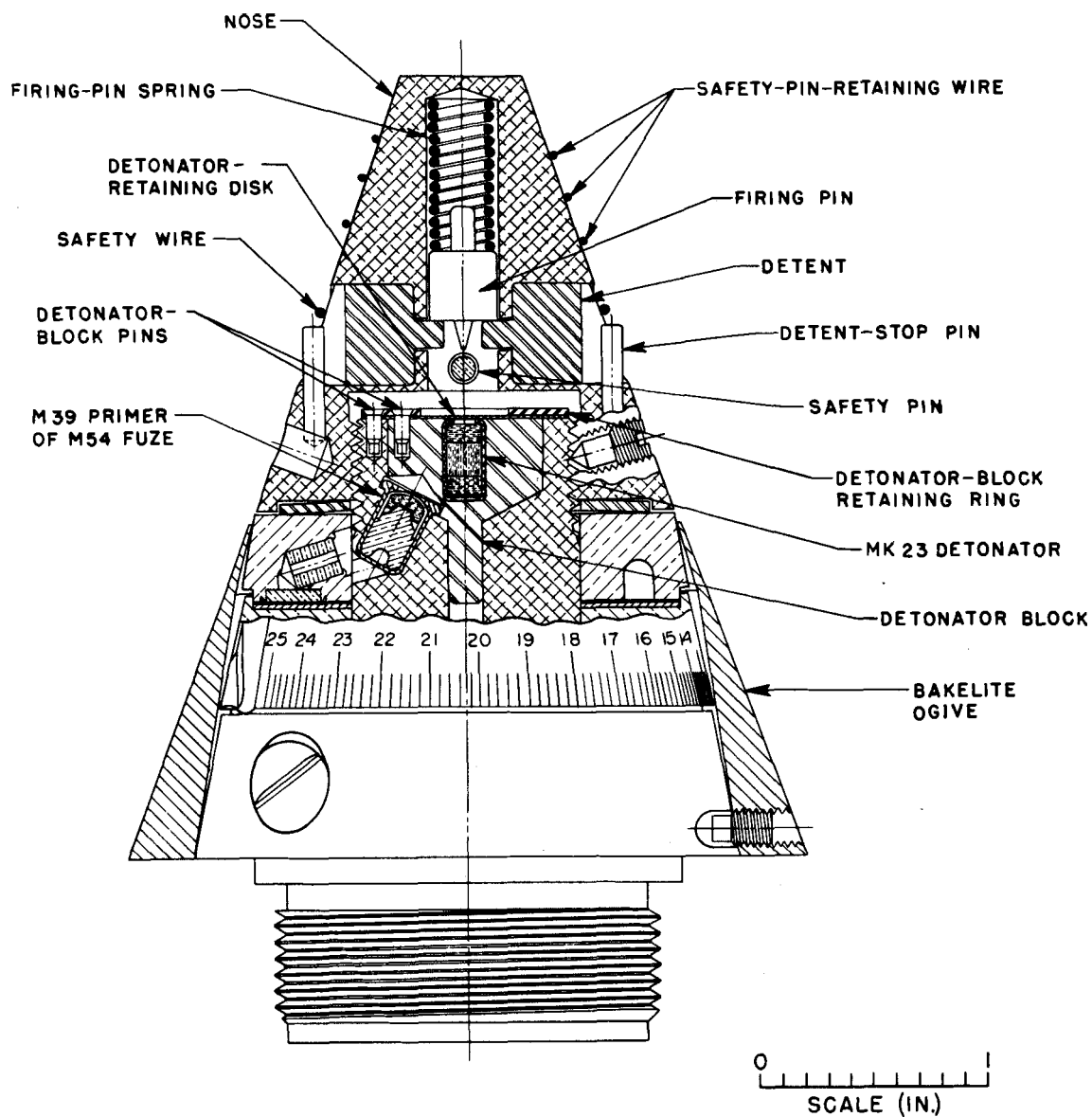
6.036. THE Mk 100 MOD 2 FUZE.—One solution to the problem of failures of the Mk 44-2 which seemed feasible was to incorporate an additional relay detonator, identical with that in the delay train, in the center of the plunger body of the delay assembly, as shown in Fig. 87. This was first tested as a possible alternative and found to give satisfactory performance in the 3.5-in./4 GPSR with a 0.05-sec delay. In the fuzes used in this test, the extra delay detonator was held in place only by NRC compound, but a simple snap ring to hold the additional detonator was proposed for standardization. This design was modified by the Naval Ordnance Laboratory to include a thin copper disk secured by drive screws to hold the detonator in place and designated the Mk 100 Type B. This was standardized as the Mk 100-2, with a 0.025-sec delay.

6.037. THE Mk 100 TYPE A FUZE.—The Naval Ordnance Laboratory proposed this design as an alternative to the Mk 100 Type B. As shown in Fig. 88, the Type A also consists of an additional relay detonator, but it uses a more powerful relay detonator (the one used in the Mk 29 and Mk 30 fuzes), which is held in a redesigned bottom-closing screw. This design was intended to be used with the Mk 44-1 aux det; and since the design seemed to offer simpler procurement problems, with the added advantage that the Mk 44-2 fuze would no longer be needed, the fuze was field tested in the 3.5-in./4 GPSR with a 0.05-sec delay assembly. The tests showed 100 per cent performance in 71 rounds.¹

6.04. TIME FUZES.—Contrary to the case with the base, nose, and aux det fuzes, there were no standard projectile time fuzes that could be used in rockets without substantial modifications, since all of the fuzes utilized gun setback forces as part of the arming process. In general there were two types of projectile time fuze available: (1) the powder-train type, with the Army M54 as an example, and (2) mechanical clock types, with the Navy Mk 18, 22, 25, 42, 50, and 51 as examples (the Army M43A3 is identical with the Mk 22). The development of time fuzes was started late, and no service fuzes were completed at the termination of the CIT rocket project, but the status of the work is discussed below.

6.041. THE RT EXPERIMENTAL FUZE.—This fuze, which is a modification of the Army M54 fuze, was made in a hurry to provide some sort of time fuze for various test purposes. It was not intended for service use, and indeed is quite unsafe for such a use. However, it was a very satisfactory stopgap, and permitted experimental testing of the ejection and ignition in various spinner flare rockets and

¹ *Performance of Mk 100 Type A Fuze with Mk 44-1 Auxiliary Detonating Fuze in the 3.5-in. SR*, W. F. Sapp, CIT/PMC 2.87, 5 August 1945, Part 1, p. 4.



EXCEPT AS NOTED ALL PARTS
ARE FROM THE M54 FUZE

FIG. 90. The RT experimental fuze, unarmed.

the determination of burst patterns for time-fuzed rockets in connection with Project Whites (see the CCISR fuze, 6.042). Some thought was given to the problem of making the RT into a service fuze, but the inherent accuracy of the mechanical types and the apparent simplicity of modifying the Mk 50-4 were sufficient considerations to cause this to be dropped.

As seen in Fig. 90, all of the M54 fuze is retained except the nose assembly and the primer striker. The detonator block containing the Mk 23 detonator (this is the same detonator used in the Mk 137 fuze) is inserted in the body, and held in by the detonator-block-retaining ring and by two pins which serve to index and hold the block in place so that the side-drilled hole is opposite the M39 primer of the M54 fuze. The 0.002-in. copper detonator-retaining disk serves to hold the detonator in the detonator block. The completely redesigned nose contains the spring-loaded firing pin supported on the two centrifugal detents. The detents are prevented from flying entirely out of the fuze by the two stop-pins in grooves in the detents. The only safety features of the fuze are the small safety wire in a groove around the outside of the nose which holds the detents in, and the safety pin directly beneath the firing pin. This safety pin is held in by a conical spring wire around the outside of the nose. A bakelite ogive as shown was provided to bring the outside contour to that of the Mk 50 fuze when desired. It can be assembled to the fuze only after the fuze has been set. When the fuze is used, it is necessary to cut the safety wire around the detents, and finally, after the round is loaded in a launcher, to remove the safety pin. The instructions to the range crews were that if the safety pin did not drop out readily the fuze was to be discarded without removing the safety pin.

When the rocket is fired centrifugal force forces the detents out, releasing the firing pin, which initiates the Mk 23 detonator, and this in turn fires the M39 primer which starts the burning of the time train.

This fuze performed very well, and no accidents resulted from its use; in all, about 300 of them were made.

6.042. THE CCISR FUZE.—Since this fuze was not finished, no tests could be made on the final complete fuze, but in view of the interim tests which indicated that the design was in general satisfactory it is discussed briefly here.

A status report¹ covers the fuze in complete detail, including a discussion of alternatives and changes in design which were considered, and the projected application.

The fuze was developed for a very specialized use, the Project Whites; this was a rocket countermeasure for suicide airplanes, which utilized the "shot-gun" technique, with the creation of a dense pattern of air bursts at very close range. As the result of some preliminary work the requirements for the fuze became (1) a series of time settings accurate to 0.20 sec or less, with a maximum time of about 2.5 sec; (2) a point-detonating nose, the more sensitive the better; (3) a shape to fit into the Model 56 head, which was to contain the Mk 44 aux det;

¹ *Final Status Report: The CCISR Fuze*, CIT/OIC 12.1, J. B. Hatcher, 5 September 1945.

- (4) the normal safety features requisite in rocket and projectile nose fuzes; and
- (5) ability to go into crash production at the earliest possible moment.

The latest design of the fuze, which was standardized for early experimental production of about 1000 units, is shown in Figs. 91 and 92. It comprises the following main parts: a sensitive point-detonating nose, a rotatable upper cap containing a spring-loaded firing pin which is locked by a ball-and-trigger mechanism held by centrifugal detents, a lower cap assembly which contains five non-obtured but sealed delay trains in a detonator block assembly, and a flash-tube block leading to the bottom closing screw assembly which contains a relay detonator.

The point-detonating nose is based on the Mk 12 fuze for the 1.1-in./75 AA, and an early test indicated that the design shown would function on 0.025-in.-thick 24ST aluminum plate at obliquities of about 60°. The detents will arm at about 5000 rev/min, but the firing-pin spring will hold the firing pin forward for setback forces up to 100 *g* and thus prevent any possibility of prematures. The nose cap serves to complete the moisture seal on the fuze as well as to hold the firing pin in place.

The upper cap assembly provides for the spring-loaded delay firing pin held by the ball. This ball rides in the groove in the trigger sleeve, being secured in place by the trigger, which is in turn locked by the detents held by detent springs.

In operation, when the rocket is fired and the spin builds up to produce sufficient centrifugal force, the detents move out, releasing the trigger; the trigger then flies out, clears the flash channel to "arm" the nose assembly, and at the same time releases the ball, permitting the delay firing pin to fall and initiate the particular delay to which the fuze has been set. In order to get as accurate and reproducible timing as possible the detent springs are designed for unbalanced arming (see 6.00).

The type of arrangement shown was found to be satisfactory so far as jolt-and-jumble tests were concerned, and to be accurate in timing, in that the firing pin dropped consistently. The objective of the over-all design was to have a distribution of air bursts within a range of about 160 ft or less; if the timing of the delay assemblies were accurate to ± 0.05 sec (equivalent to ± 40 ft of range) then the accuracy of their initiation (which is determined by the time when the firing pin falls at the completion of the arming process) would be ± 40 ft of range. Nine field-fired rounds all functioned (or "armed") between 126 and 168 ft, with a mean of 150 ft and a mean deviation of 10 ft, a result far better than expected.

In the lower cap assembly the lower cap is held to the upper cap by means of the snap ring, which is backed by the tension washer of the Belleville type. This very simple arrangement is possible because of the low angular acceleration of the rocket and the small inertia of the upper cap; although the upper cap can be rotated by hand, it does not rotate when the rocket is fired. The setting pin held by the setting-pin spring provides an additional factor of safety in preventing such rotation, and serves to index the delay-detonator housing directly with respect to the delay firing pin; it also permits setting the fuze simply by counting the number of clicks as the upper cap is rotated. Moisture sealing at this joint is of

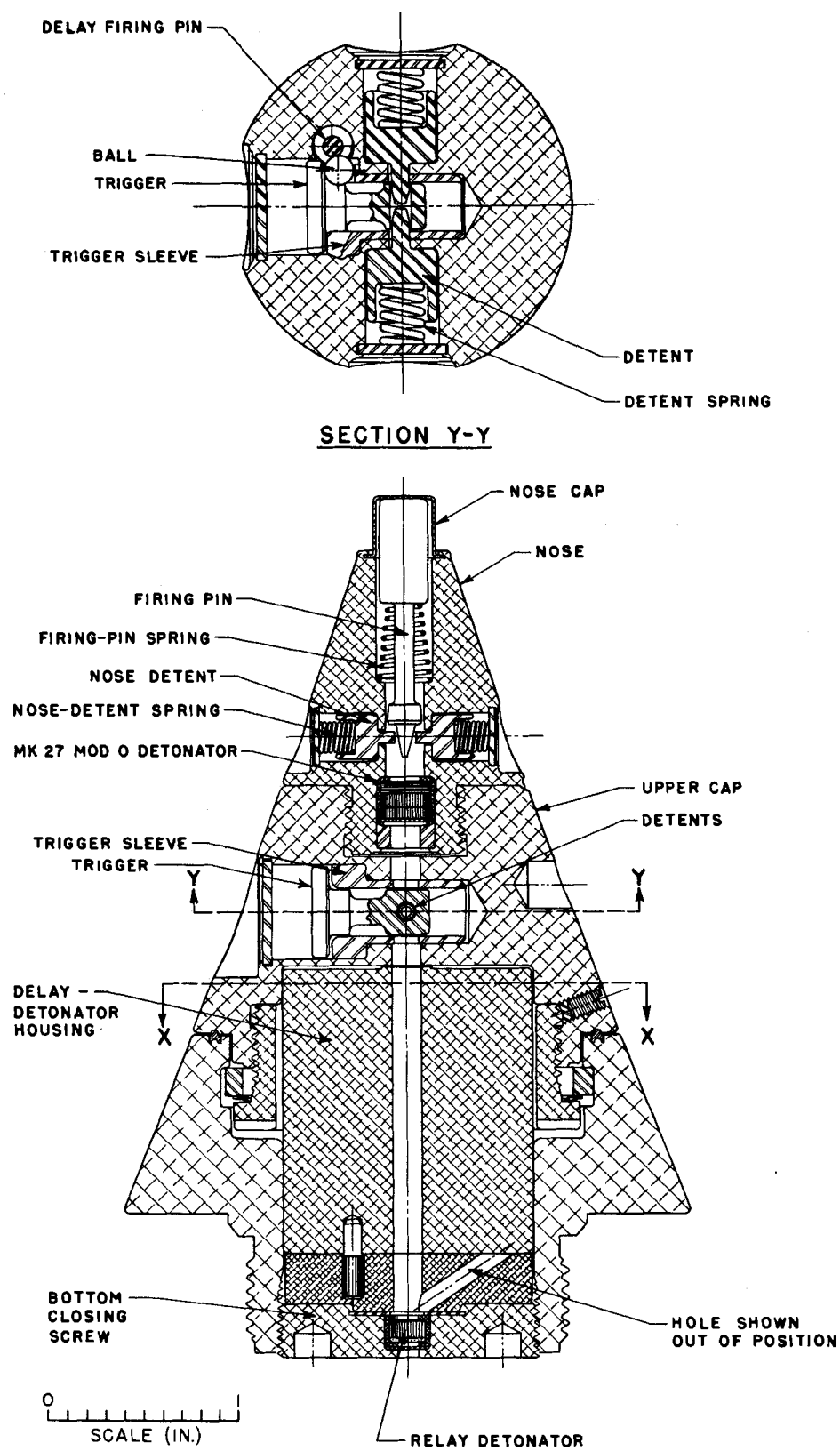


FIG. 91. The CCISR fuze, unarmed.

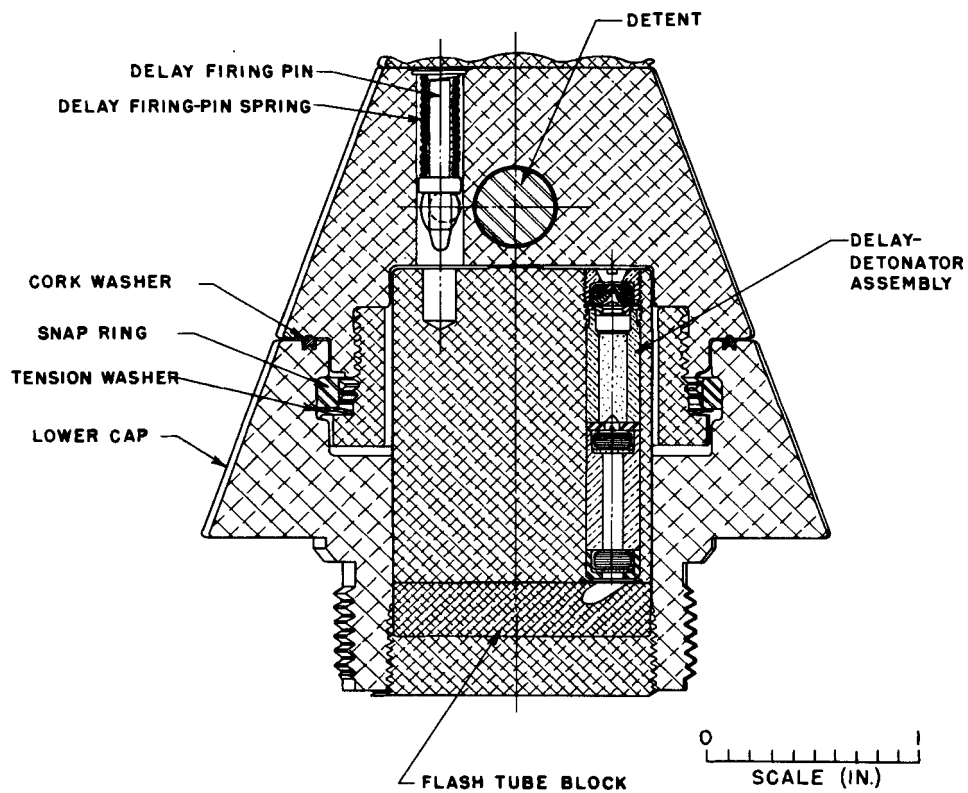
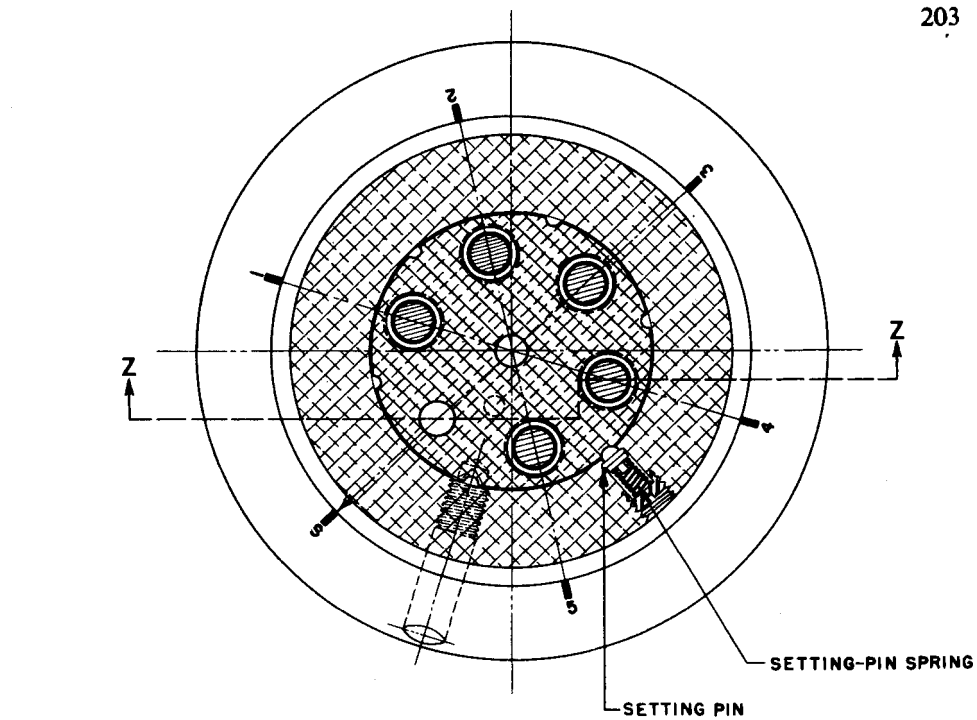


FIG. 92. Partial views of the CCISR fuze, unarmed.

the same type as that used on standard projectile mechanical time fuzes, with the cork washer in appropriate grooves.

The delay detonators were never tested in the fuze itself, but nearly 500 were fired statically to establish the design. Actually the design is identical with that in the Army M48 fuze (see the Mk 100, 6.034), and it made use of Army components wherever possible, except that the delay pellet and its tube were made longer, and some changes were made in the arrangement at the bottom of the delay tubes to simplify procurement. The delay shown in the figure is one of the shorter time delays with a flash tube leading to a second relay detonator; in the longest delay (which gave a time of about 2 sec, with an expected mean deviation of about 0.05 sec), the delay tube runs the full length of the housing, and only the lower of the two relay detonators is used.

The final relay detonator in the bottom-closing screw, which is initiated by either the nose detonator or the delay to which the fuze has been set, is the same as the relay detonator in the Mk 29, Mk 30, and Mk 100 Type A fuzes.

6.043. THE CTSR FUZE.—With the development of the first 5.0-in. spin-stabilized flare rocket it was clear that a time fuze for spin-stabilized rockets would be required, and it was considered desirable to have the inherent accuracy of a mechanical time fuze as contrasted to the powder train delay types. It was thought that the simplest practicable approach would be to modify some existing projectile mechanical time fuze, and from an examination of the general design features of the projectile fuzes then current and available, it was clear that any design based on them would require (1) removal of the setback pin and (2) design of an arrangement to provide for disengagement of the setting pin from the timing disk by centrifugal force. These two changes were necessary, since in projectiles the setback pin slides down and the hammer forks mash the setting lug out of engagement with the setting pin under the influence of the gun setback forces of 3000 g or more, while the rocket setback forces are only 30 to 60 g.

The Mk 50-4 was considered a suitable fuze; however, when the setback pin is removed from this fuze it is possible for the fuze to start, and run, solely as a result of any slight sidewise blow that disengages the safety lever from the clock escapement (provided, of course, that the setting pin is already disengaged). In order to provide adequate safety the design was planned to include, in addition to the two features mentioned above, a third arrangement, to lock the safety lever against a blow. A preliminary test was made by removing the setback pellets, setting the fuze, and mashing down the setting lug by hand at the range just before firing. This test showed that the clock mechanism behaved satisfactorily at short time settings. The maximum and minimum time of functioning in 13 rounds were 1.92 and 1.45 sec respectively, with all fuzes set at 1.0 sec; the mean deviation of the time to burst was 0.095 sec, which is six times the mean deviation of the flight time to the average range; the setting could not be made more closely than about 0.15 sec.

It is unfortunate that the Mk 50-4 was not tested at longer times or in the 5.0-in. PySR, for after the development was essentially complete it was found that the clock itself would not run reliably for more than a few seconds. However,

the features of the modification described above were themselves quite successful, and with the appropriate combination of clock and rocket the design should be perfectly satisfactory. A complete report on this fuze¹ which discusses in detail the various design and testing problems encountered is available.

The final form of design incorporating these three features is shown in Figs. 93 and 94. The upper and lower caps of the Mk 50-4 are revised to a one-piece nose; the outside shape remains essentially the same. (It would be possible to put the same mechanism in the Mk 30 shape, if this were desired.) The setting pin has been redesigned so that its disengagement is accomplished by the setting-pin spring. In the unarmed fuze the setting pin rides against the tip of the trigger, which is locked by the two centrifugal detents which in turn are held by the detent springs. To assist in adequate sealing for moisture-proofing of the fuze the detent springs and the trigger are enclosed by cups, and sealing compound can be used between the cups and sealing disks. The central hole in the nose provides space for a drying agent.

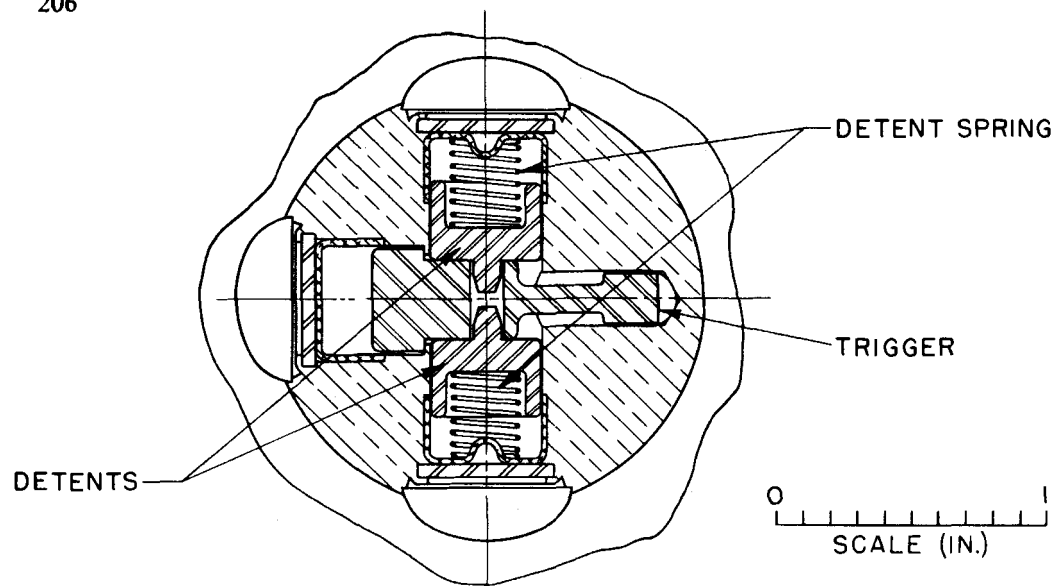
The modification of the Mk 50-4 clock mechanism is shown in Fig. 94. The safety cam, which is held in the *unarmed* position by the safety-cam spring, has been added. The safety lever has been altered as indicated to include the tip, which locks against the safety cam, and the mass of this lever is substantially reduced; in addition, it is held in the *unarmed* position by the safety-lever spring. This particular arrangement is not capable of much variation, and tolerances have to be close in order to maintain effective locking of the tip of the safety lever and still avoid the adjusting screw when locating the safety cam pivot pin; however, it was found to be quite satisfactory. Originally a somewhat simpler arrangement with a different cam and safety lever was worked out, in which the three new pins were mounted to the third plate, rather than to the first plate as shown here. However, this would require considerable disassembly of the clock, including the firing pin and spring, whereas the present arrangement can be installed in a complete and finished clock by holding it in a simple jig and reassembling.

The operation of the fuze is as follows: When the rocket is fired the spin velocity increases during the course of the burning from zero to the full value (about 7000 to 7500 rev/min for the 5.0-in. PySR, for which the fuze is intended). When the spin reaches about 4400 rev/min the trigger moves out from on top of the setting pin, and the setting pin is then snapped up and out of engagement with the timing disk. Finally, when the spin reaches about 6500 rev/min the safety lever moves out of engagement with the escapement lever and starts the clock.

The field testing was focussed on three factors: (1) behavior of the setting-pin release mechanism by itself, (2) functioning of the safety lever mechanism by itself, and (3) over-all performance of the entire fuze.

All of these tests were made with plaster-loaded heads with holes drilled in the nose, and with a flash-powder smoke-puff as an indicator of functioning. Tests of (1) were made by firing fuzes in which the clock was replaced by a Mk 51-2 clock from which both the escapement and all of the timing disk except the setting

¹ *Final Status Report: The CTSR Fuze*, CIT/OIC 12.1, J. B. Hatcher, 26 September 1945.



SECTION X - X

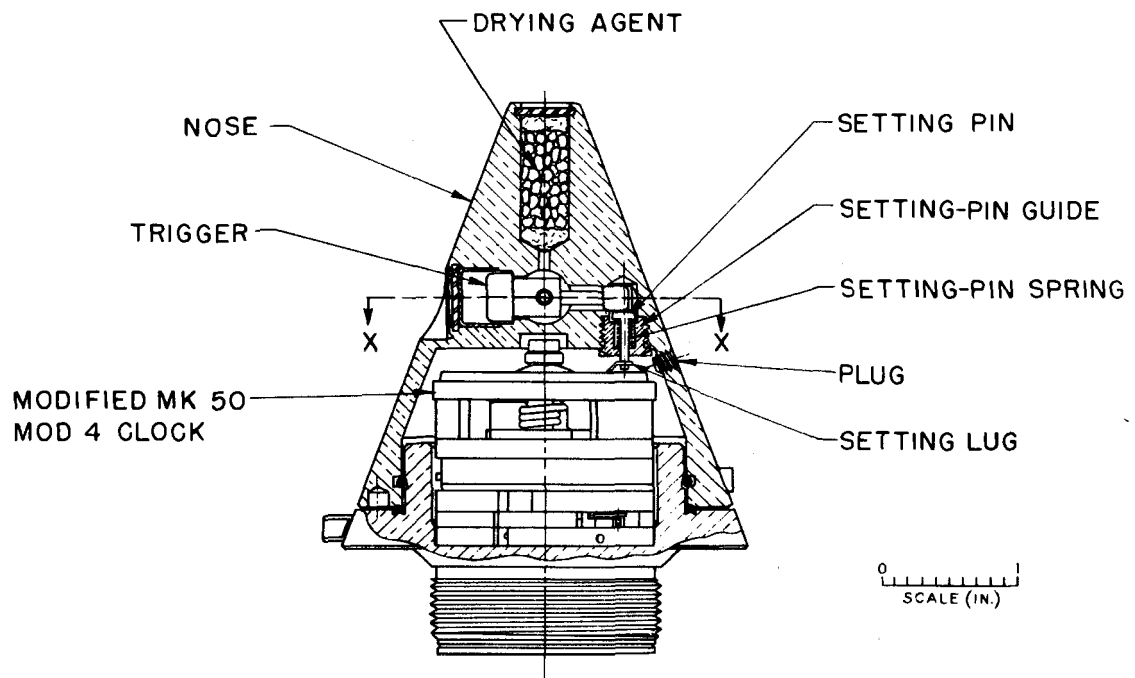


FIG. 93. The CTSR fuze, unarmed.

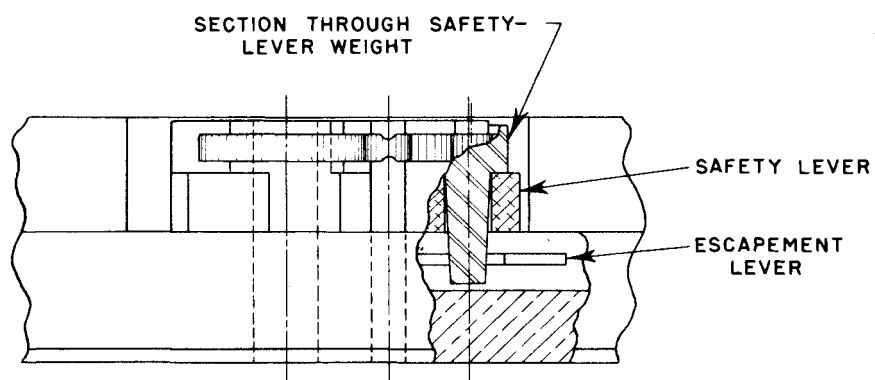
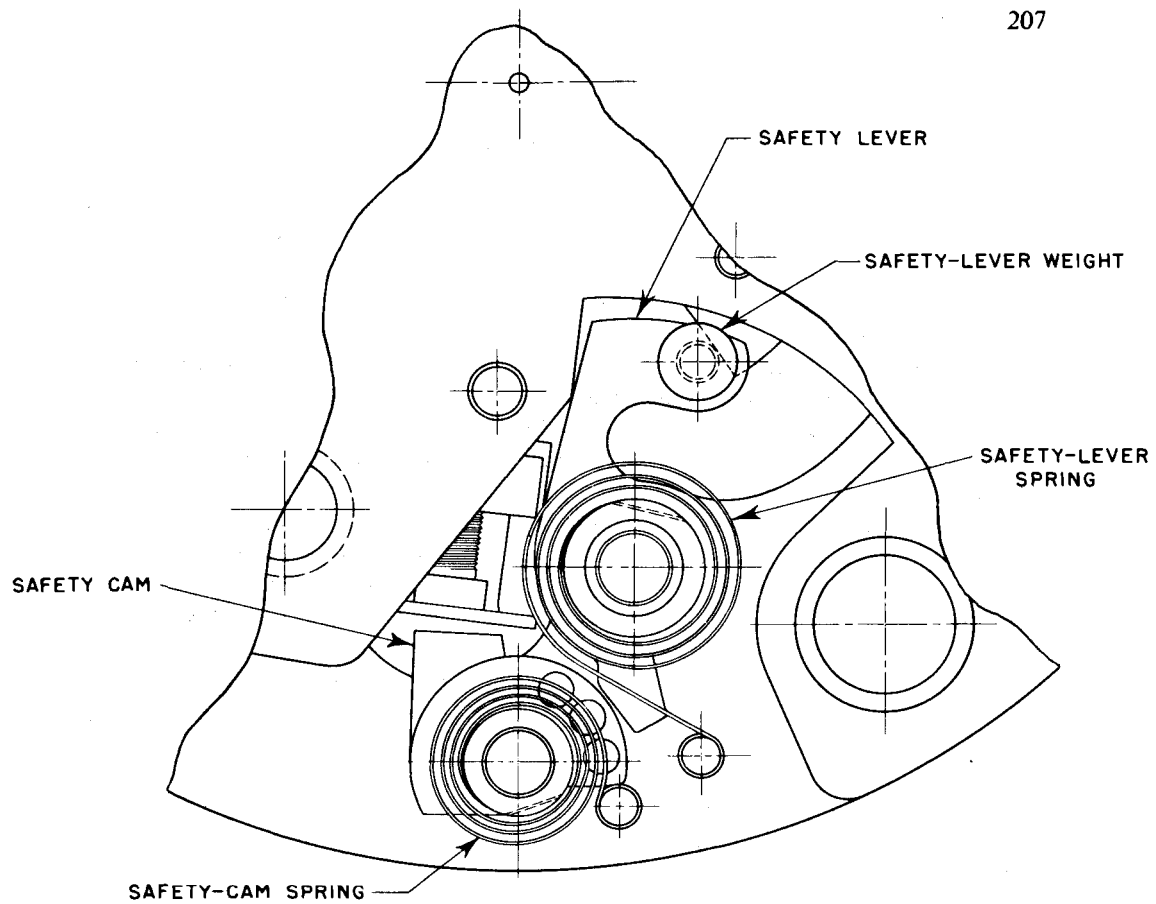


FIG. 94. Cam and safety-lever assembly of the CTSR fuze, unarmed.

lug had been removed; thus, in these fuzes the firing pin would fall almost immediately after the setting pin snapped out of the timing disk. Tests of (2) were made by firing fuzes which were set so that functioning would occur as soon as the firing arm elbow cleared the safety disk; the fuzes had the setting pins removed.

It was anticipated in the design, and borne out by the tests made, that it would be necessary for the setting pin to be disengaged before the clock started, since otherwise the clock would start and then jam as the timing disk caught on the setting pin, and the clock would not restart after the setting pin was removed, except as a result of a blow or impact.

In a field test of ten rounds, made as described in (1) above, the setting pin was shown to come out at a spin velocity of from 3400 to 4800 rev/min, with an average of 4120 and a mean deviation of 340 rev/min. These figures exclude one round in which the pin removal was at 6620 rev/min, apparently because of abnormal friction somewhere.

It was in the design of the safety lever itself that the angular and forward acceleration were found to play some part; thus, in the case of two early designs of the lever, one lever swung out, when tested statically, at about 2200 rev/min, and the other lever, which was of a different shape and slightly lighter, at 3000 to 3500 rev/min. But when these were field tested [as in (2) above, with no setting pins], the clocks with the heavier lever functioned later than those with the light lever. Some of this effect could be due to forward acceleration, but rough calculations indicated that the angular acceleration was probably the important factor; the difference in weight of these levers was very slight, and the difference in behavior was due mainly to the shape.

TABLE 5. Behavior of CTSR fuze.

NUMBER OF ROUNDS	MOTOR TEMPERATURE	FUZE SETTING	MEAN TIME FROM LAUNCHING TO FIRING	NUMBER OF DUDS
	(°F)	(sec)	(sec)	
5	0	1	1.96	0
4	70	1	2.13	1
5	130	1	1.44	0
2	0	2	3.0*	0
2	70	2	2.6*	0
4	130	2	2.4	0
1	130	5	—	1
1	130	7	7.8	0
5	0	10	11.5	4
10	70	10	10.8*	2
3	130	10	10.7	1
2	0	20	23.1	0
5	70	20	21.4	2
4	130	20	20.6	2

* Excluding one round in which the time was extremely long.

The lever-spring combination shown in the figures operates at static spins of 6000 to 6500 rev/min, and gave very satisfactory and reproducible times in tests as in (2) above.

Only 53 complete fuzes have been field fired; their behavior is shown in Table 5. The photographic data for these rounds are incomplete, and consequently the times, which are based on stop-watch observation, are not particularly accurate.

The single dud in the short time settings (1 and 2 sec) clearly indicates that the design features are essentially satisfactory; the high per cent of duds at the longer ranges is due to two causes, one of which is failure of the clock mechanism itself. This type of failure is apparently due to a combination of the down-range nutation forces, possible malalignment of the clock with the spin axis, and the lower spin at the longer ranges. That this behavior is inherent in the clock mechanism itself and is not due to any of the modifications was shown by firing rounds containing standard unmodified Mk 50-4 fuzes (with setting pin and setback pin removed) which were set for the longer times of 10 and 20 sec; these rounds were all duds. The second cause of the duds was that the firing arm had not rotated to move the elbow lug into the firing notch (the duds were found with the notch past the firing elbow by one or more seconds); this could be readily corrected by the addition of a spring to the firing arm to assist the apparently insufficient centrifugal force, as in the Mk 61 fuze clock. If the Mk 61 fuze is available it might be more satisfactory to modify than the Mk 50-4.

Chapter 7

ANTISUBMARINE ROCKET FUZES

7.00. INTRODUCTION.—The development of the rocket-propelled antisubmarine contact bomb early in the war necessitated the design of suitable fuzes adapted to the low setback forces and absence of spin characterizing the new motive power. The British had originated for their shipboard mortar-like Hedgehog ammunition a simple type of underwater vane-arming, inertia-firing fuze, the No. 420, which in addition to being directly applicable to similar American ammunition, appeared to be readily and quickly convertible to rocket-driven rounds. Production of a nearly identical fuze, the Mk 136, with the slightly modified design for rocket projectiles, the Mk 131, was begun by the U. S. Navy, but persistent British reports of premature fuze operation appeared to emphasize the need for a new fuze operating on different principles. Accordingly, the pressure-arming, inertia-firing Mk 135 fuze was originated at CIT and placed in limited production. The request for a smaller, lighter fuze, more adaptable to volume production but operating in the same manner as the Mk 135, to replace the Mk 131 and 136, led to the design of the Mk 140 fuze. Before the latter could be developed fully, the Mk 131 and 136 fuzes became available in quantity, and partly loaded samples from each lot of 2000 were sent to CIT for a determination of the underwater performance as a part of the acceptance testing procedure which the Navy specified for the fuze. The unsatisfactory operation of the vane-arming fuzes as demonstrated by these tests spurred the development of the Mk 140 as a replacement, and plans were laid to put it in production at several locations. Before tooling was completed, however, the reasons for performance failures of the Mk 131 and Mk 136 fuzes had been discovered; the defects could be corrected to a large degree by simple changes in the many thousands of loaded fuzes immediately available in storage. Modification of the Mk 131 and 136 fuzes and production of the Mk 140 proceeded simultaneously, and numerous samples of each were sent to CIT for the underwater phases of the acceptance tests. The test results showed that the performance of the modified Mk 131 and 136 fuzes was acceptable, while that of the Mk 140 was unsatisfactory. The latter fuze, which had also proved difficult to manufacture, was then abandoned and the Mk 131 and 136 were redesigned to incorporate many of the improvements found necessary in the underwater tests. The new vane-arming fuzes, designated Mk 156 and 158, were produced in quantity shortly before the end of the war and gave excellent performance in the acceptance tests. Some development of the Mk 140 was continued after its abandonment, in order to correct the defects with the fewest possible alterations to the internal mechanism, and to render the fuze useful for applications unsuited to the vane-arming type. Although this development was not completed, preliminary tests indicated that the major difficulties had been eliminated and the fuze made adaptable to a wide variety of projectiles.

The Mk 139 fuze was developed in 1942 and 1943 to meet the special require-

ments for the fuzing of retro-bombing projectiles. It is a spring-arming, point-detonating type, intended for antisubmarine rockets dropped vertically from low altitude by aircraft. It is designed to be useful against both submerged and surfaced submarines, as the fuze is armed before entering the water and the firing mechanism is water-discriminating. Although successful in operation, the fuze was not produced in large numbers because of the gradual abandonment of retro-bombing.

7.001. TESTING OF UNDERWATER FUZES.—Before the specific fuzes are described in detail a brief summary of the testing procedures and equipment involved in ascertaining the operating characteristics of underwater fuzes will be given. The mechanical underwater nose fuzes investigated by CIT, divided into groups according to the principles of arming and firing, are listed as follows:

UNDERWATER NOSE FUZE TYPES	
ARMING METHOD	FUZE
1. Arming wire, setback, and mechanical time delay..	Mk 139
2. Arming wire, and water pressure acting on a bellows	Modified Mk 144
3. Water pressure acting on a diaphragm.....	Mks 135, 140, 142
4. Setback, and underwater travel turning vanes that will not turn in air.....	Mks 131, 136, 156, 158
5. Air travel that will turn light free-running vanes coupled with a gear-reduction system.....	Mk 141
FIRING METHODS	FUZE
1. Point-detonating (direct contact with a fuze member)	Mks 139, 141, Modified Mk 144
2. Inertia-firing (release of spring-loaded firing pin by impact forces acting on a weight).....	Mks 131, 135, 136, 140, 142, 156, 158

All of the foregoing fuzes were designed primarily for shipboard use except Mk 139, Mk 142, and the original Mk 144, intended for aircraft installations.

7.002. TEST PURPOSES.—The early underwater test activities were divided into two distinct classifications—acceptance tests, carried out under Bureau of Ordnance specifications, and experimental activities for the trial of new designs and design modifications. The acceptance tests, made with partially loaded samples from each manufactured lot of 2000 fuzes, were intended to indicate the probable performance in actual service, the assumption underlying the test procedures being that while the fuze design was satisfactory, a few manufacturing errors not detectable in routine inspection might creep into production. Because of the small percentage of failures anticipated the underwater phase of the tests was originally specified for only four fuzes from each lot, and was to be a single over-all test to determine only whether each fuze armed and fired. The large percentage of failures actually encountered, however, together with the necessity for determining in a rapid and precise manner the exact reasons for failures, led to the adoption of new procedures. The present methods are based on an analysis of the arming and firing mechanism of a particular fuze, followed by the formulation of separate tests to determine as far as possible the operation of each functional part of the

mechanism independently of the rest. While these multiple tests require more time, fuzes, and rocket motors than the single-test method, the results not only provide simple statistical information on over-all fuze performance and a close check on the manufacturing processes, but also yield definite data on the fuze design itself, which can be of valuable assistance in making improvements. For these reasons the multiple-test method has been retained for acceptance work, even when nearly perfect fuze operation is assured; and no fundamental distinction any longer can be made between acceptance and experimental testing procedures.

7.003. TEST FACILITIES.—The equipment and operating personnel of another group, engaged in studies of projectile underwater behavior at Morris Dam, were made available for fuze work on a part-time basis. The facilities consisted essentially of a horizontal target structure which could be set at any desired depth to a limit of 170 ft by means of an electric hoist or raised to the surface for recovery of test rounds, adjustable launchers for firing rocket-driven rounds downward into the water, and an acoustic range. The target was arranged in the form of a shallow, 20-ft-square wooden box usually kept filled with sand, surrounded by a strong wire screen which increased the size of the target useful for recovery purposes to a square approximately 50 ft on a side. The launchers having a QE of about -45° were provided with gates for holding the rounds in place until pushed open by the rocket motor thrust. An electrically-released projectile-dropping device was also available, suspended from a high line at adjustable elevations up to 150 ft directly over the target. Since the launchers had to be located close to the water because of structural limitations, the rocket burning distances were required to be so short that a thermostatically controlled oven was necessary for heating the motors. The acoustic range was rarely used for fuze work.

7.004. TEST PROCEDURES.—It will be noted from the arming methods given under the tabulation of fuze types in 7.001, that in many instances a part or all of the arming is accomplished on the launcher or shortly thereafter during air flight. This part of the arming sequence can usually be studied to advantage by entirely separate tests made on a land range, simplifying the equipment and avoiding difficulties with firing accuracy involved in the water range. The fuze water-range problems thus become in general a determination of prematuring tendencies on water entry, the depths at which fuzes become fully armed, and finally the firing performance against various underwater targets.

The methods of determining the underwater characteristics of the fuzes listed above were essentially similar in spite of the widely different mechanical principles involved in arming. Prematuring tendencies were determined in the early days of fuze work by the floating-bomb technique, in which the fuze was mounted in an empty reinforced head of sufficient length to float the complete round, including the fired motor tube. While this procedure had the advantage of making the launcher location independent of the recovery target, allowing unlimited burning time, the deceleration values on water entry were quite different from those experienced by a round of standard weight, and this method was therefore abandoned. A small-mesh fishing net, supported 15 ft above the recovery target and submerged to between 25 and 50 ft, was next tried and found to be quite satis-

factory for prematuring tests of the pressure- and propeller-arming fuzes of the inertia-firing types, mounted in standard inert heads of normal weight. The life of the net was satisfactory in spite of the strains imposed by the tests. A third technique was later devised, however, which has proved widely applicable in determining all the effects of water entry on fuzes which might be damaged or disturbed from their final underwater armed condition by contacting even a net at terminal velocity. This method consisted of attaching a strong small-diameter cord to the shroud ring of a round of standard weight, the other end of the cord being tied to a long helical spring attached to the high-line dropping mechanism at a point above and somewhat beyond the point of projectile water entry. The purpose of the spring, later replaced to advantage by a glider towing cable made of rubber and fabric, was to provide a known, low value of deceleration in bringing the round to rest under water, much less than the value required to fire the fuze. A round could be recovered easily and rapidly by hoisting the dropping mechanism until the round was brought up out of the water to the level of the working platform. Since the fuzes contact nothing but the water and the rounds are not handled prior to inspection immediately following recovery, the test results are clear and free from question. Use of the captive round has enabled accurate results to be obtained with all the fuzes listed above, including the sensitive point-detonating types, and has led to the discovery of several obscure causes for fuze arming failures. The method has been used successfully with heavy bombs which cannot be stopped by the net. At the highest entry velocity so far used in fuze tests, photographs show no increase in projectile yaw at water entry.

Determination of arming depth for inertia-firing fuzes, which must complete their final arming process under water, has been made by firing the fuzed rounds against the target at various depths. Since the fuzes cannot fire until they are fully armed, an approximate value of arming depth is obtained if a sufficient number of tests are made. A sand target was originally used but was found to be less satisfactory than a sheet-metal target, which eliminated any questions of how much was the effective target depth and whether the impacts were always great enough to fire insensitive fuzes. In the case of pressure-arming fuzes, where prematuring is avoided by a slow increase of pressure within a cavity retarded with respect to the external pressure, it becomes quite essential to measure the arming depth by firing the fuze, since it may arm after coming to rest on the target. At water entry velocities higher than about 250 ft/sec, or for very shallow arming depths the sand alone will insure normal fuze firing, saving the target structure from the severe impacts.

Attempts to use the acoustic range for arming depth determination proved disappointing except when rounds were dropped into the water from low elevation. The entry splash at velocities around 175 ft/sec apparently masked the firing of electric squibs and even tetryl boosters to depths of as much as 20 ft, which was usually beyond the range of normal arming depth; however, it is not considered that the few trials were at all conclusive, and the acoustic method, if developed, could become an extremely useful tool.

The firing sensitivity of all types of fuzes, except the Mk 141, has been determined by dropping fuzed inert-weighted rounds from a few feet below the water

surface onto suitable targets submerged to about 60 ft, where the rounds have attained constant terminal velocity. For axial-sensitivity tests, the target consisted of a strong steel structure supporting a series of battens, resembling the decking of the captured German submarine, the *Graf*. The deck should constitute the most resilient surface of appreciable area, disclosing the fuze sensitivity necessary for approximately 100 per cent firing. This target was assembled from 1¼-in. by 3-in. net clear, vertical-grain Douglas fir battens, spaced 0.75 in. apart and clamped tightly to the 3-in-wide end members of the heavy steel framework, leaving a batten span length of 24 in. between supports. The frame was so constructed that when placed in the recoverable target box it located the horizontal batten target about 2 ft above the surface of the sand. While a scattering of rocket impacts relative to the batten supports was desirable in some investigations, it was usually important to have the impacts cluster in the most resilient section of the target, close to the center of the 2-ft span. In calm weather a surprisingly high percentage of hits within 2 in. of span centers could be obtained if the rounds were steadied and the target allowed a few moments to come to rest after stopping at the 60-ft depth. With a slight wind, however, and at other times for unknown reasons considerable difficulty was experienced in hitting the span centers frequently enough for significant sensitivity tests. Since only about 80 drops could be made in one day, and since these routine tests prevented other use of the target, a small deck installation was made in one of the valve gate wells of the Morris Dam gatehouse where the water was undisturbed regardless of weather conditions. It was found, however, that raising or lowering the open target in the well created a disturbance in the water which instead of damping out quickly persisted for from 30 minutes to an hour, preventing any accuracy in striking the target. This experience indicates that a successful installation of this type probably could not be made in a tank or other confined volume.

Some attempts were made to guide the standard rounds to the deck target, first by enclosing the round in four tightly stretched wire cables suspended from the working platform and passing through the recovery target to suspended weights, and second, by passing only two weighted cables through four small eyelets welded to opposite sides of the bomb and motor shroud, using fins with zero pitch angle. The first method permitted too many rounds to escape between the wires; the second showed some promise of success in repeatedly striking the center of a single slat, but was subject to erratic operation on occasion and was temporarily abandoned pending changes in projectile mounting and guide-wire tension.

For determining fuze sensitivity to glancing impacts, a 4 by 6-ft plate of ½-in. steel was rigidly mounted on but above the recovery target and arranged for an adjustable incidence angle. The rounds were dropped much as they were in the deck tests. A small net was suspended below the plate and well above the bed of the recovery target to bring the rounds to rest, subsequent to plate impact, with deceleration less than that required to fire the fuzes. Since the same plate was used repeatedly, it was given a coat of paint after every few test drops to show where the rounds struck, preventing any possibility of including hits on the top edge of the plate in the test results.

7.01. HIR (Mk 135) FUZE

Rockets in which used

ROCKETS FOR SHIPBOARD USE

- 7.2-in. Rocket Mk 1, with 2.25-in. Motor Mk 1 (Mk 1 grain) and 7.2-in. Head Mk 1. Total nominal weight of rocket, 60 lb.
- 7.2-in. Rocket Mk 2, with 2.25-in. Motor Mk 3 Mod 1 (Mk 1 grain) and 7.2-in. Head Mk 1. Total weight of rocket, 60 lb.
- 7.2-in. Rocket Mk 4, with 2.25-in. Motor Mk 3 (except Mk 3 Mod 1) (Mk 2 grain) and 7.2-in. Head Mk 4 (except Mk 4A). Total weight of rocket, 65 lb.

ROCKETS FOR AIRCRAFT USE IN RETRO-BOMBING

- 7.2-in. Rocket Mk 3, with 2.25-in. Motor Mk 3 Mod 1 (Mk 1 grain) and 7.2-in. Head Mk 3. Total rocket weight, 60 lb. A nominal entry velocity of 175 ft/sec was specified.
- 7.2-in. Rocket Mk 5, with 2.25-in. Motor Mk 3 (except Mk 3 Mod 1) (Mk 2 grain) and 7.2-in. Head Mk 4 (except Mk 4A). Total weight of rocket, 65 lb. A nominal entry velocity of 175 ft/sec was specified.

OTHER USES

The fuze was designed for use also in Hedgehog ammunition.

Dimensions and weight

The over-all dimensions, weight, and mounting-thread details are given in the outline drawing.

Materials

Materials used for the essential parts are brass castings QQB-691a-2 Composition 11, or free turning brass rod for the external parts (except the die-cast tetryl cap); brass rod for the internal nose plate, body, posts and sleeves, shutter, and tetryl disk. The diaphragm is made from Grade A spring phosphor-bronze sheet, while the bell cranks, striker head, and firing pin are of steel.

Explosive components

Detonator: instantaneous
Lead-in: tetryl
Booster: tetryl (30 gm)

General arrangement drawing

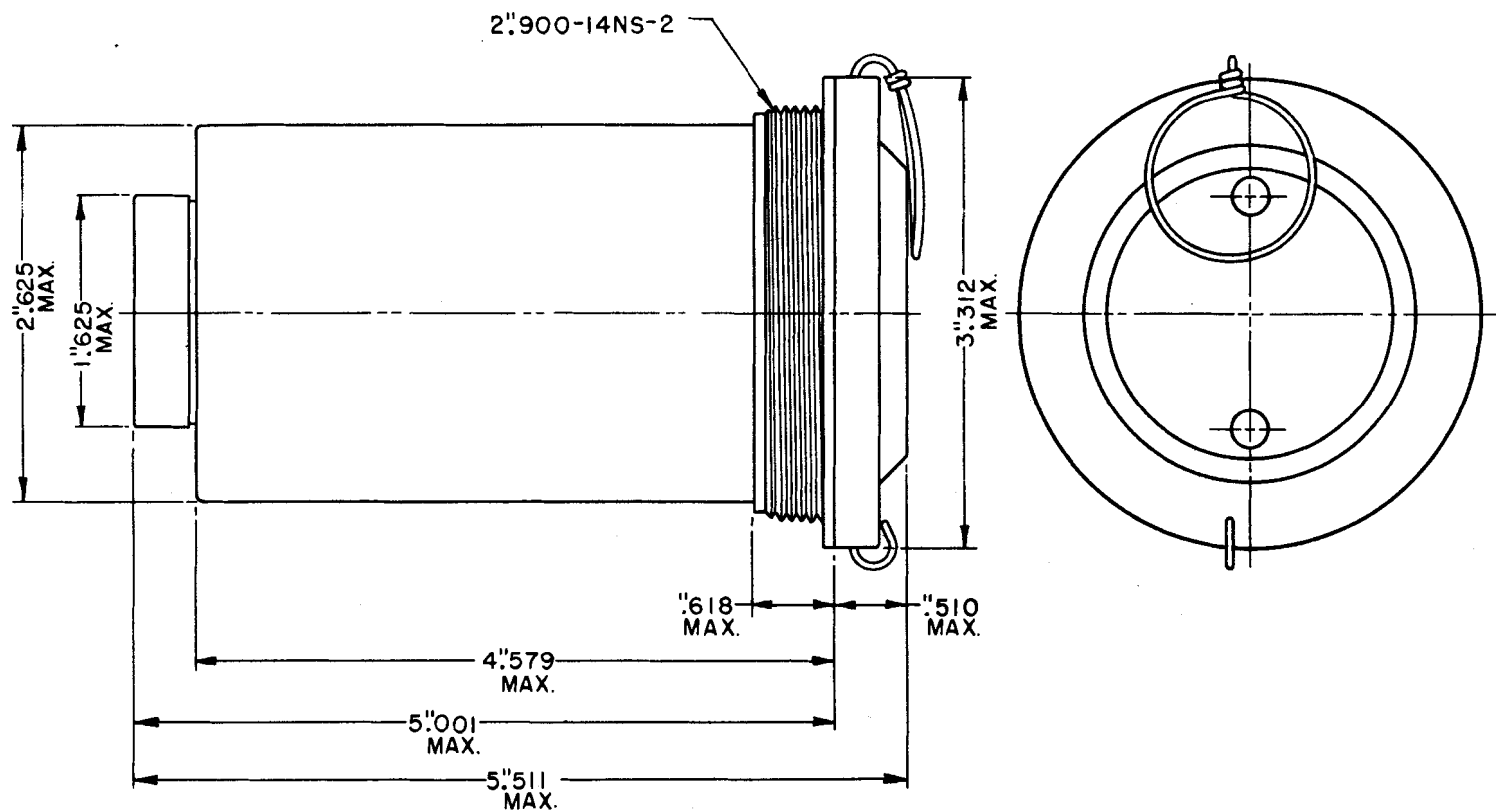
BuOrd Drawing No. 330039

7.011. GENERAL.—The original Mk 135 fuze was sometimes referred to as the HIR fuze, the letters designating the operating principles (hydrostatic arming and impact firing) used in rocket ammunition. A static arming pressure of between 10 and 15 lb/in.² was specified for fuze production, corresponding to a head of water between 23 and 35 ft, and the fuzes would generally arm at these depths if the ammunition were simply dropped overboard. However, at the normal entry velocity of 175 ft/sec and entry angle of about 45°, the fuzes would arm at a depth

of between 7 and 15 ft, because of the dynamic pressure built up on the projectile nose during the deceleration period following water contact. Functioning of the fuze would take place upon impact with a solid object such as the hull of a submarine or other well supported superstructure at angles up to about 75° from normal, when the projectile was descending under water at its terminal velocity of 23 ft/sec.

The Mk 135 Mods 1 and 2 are very similar to the original Mk 135 except that the sensitivity was increased to insure firing over virtually the entire submarine superstructure, and, to avoid prematures due to the increased sensitivity, the specified static arming pressure range was increased to between 17 and 22 lb/in.², corresponding to water heads of 39 to 51 ft. The higher range of arming pressure increased the arming depth to between 11 and 20 ft under normal entry conditions; most of the fuzes armed within this range, but some having arming pressure in excess of 19 lb/in.² failed to arm in the dynamic pressure wave and descended nearly to the depth producing the required static arming pressure before fuze arming occurred. The Mod 2 differs from the Mod 1 in one change that was made to facilitate manufacture and in another detail to provide positive arming.

7.012. MECHANICAL DESIGN.—The firing mechanism mounted in the fuze body comprises a spring-loaded firing pin which is retained by three locking balls confined by the surrounding striker head, or inertia weight. Unlocking of the firing device is effected by the arming mechanism, which is mounted in the fuze nose except for the safety sleeve and shutter located in the body. The relatively heavy shutter, which in the *unarmed* position holds the detonator over a safety vent leading to the fuze interior, is driven by two long coil springs of low spring rate and is secured by the shutter detent when in the *armed* position. Two bell cranks, interlocked by the diaphragm button and pivoted between the two halves of the split nose plate, serve to hold both the shutter and striker head in the *safe* position until the cranks are pushed outward and retained with crank detents against the fuze can interior, by inward motion of the diaphragm. The phosphor-bronze diaphragm is die-formed into a conical shape so that when clamped tightly around its outer edge between the fuze can and nose cap a snapping action is obtained, with little inward motion from the *unarmed* position taking place until a certain minimum pressure within the nose-cap cavity is exceeded, when the diaphragm suddenly inverts. Rupturing of the diaphragm from high water pressure at extreme depths is prevented by the formed nose plate, on which the diaphragm is supported if forced beyond the *armed* position. The safety sleeve, sliding freely on the body, engages hooks on the bell cranks at both ends of its travel; thus it aids by its inertia in preventing premature fuze arming caused either by the large acceleration of Hedgehog rounds, or by deceleration at water entry. Spacing and alignment of body and nose plate are effected by four posts and sleeves located on a circle of diameter large enough to allow the striker head to rock off the body in any direction and fire the fuze without interference. The nose cap is provided with two holes for water entry, drilled $\frac{1}{8}$ in. in diameter to a 1-in. depth, followed by $\frac{1}{16}$ -in. holes passing through the center and intersecting the hole drilled to admit the grooved diaphragm button nut. The port holes allow a safety wire, which also



WEIGHT---- 5.1 LB

FIG. 95. Outline view of Nose Fuze Mk 135 Mod 2 (HIR).

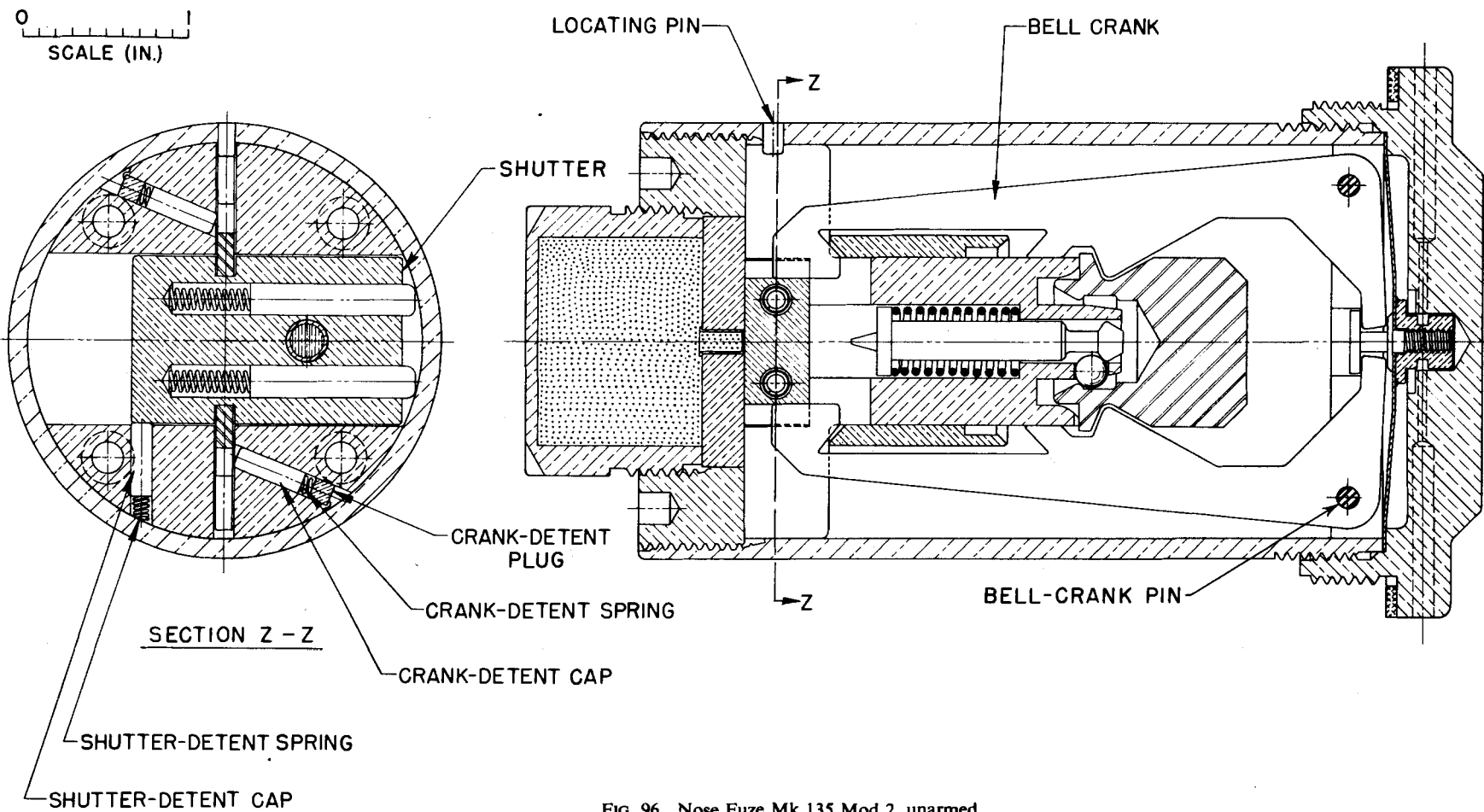


FIG. 96. Nose Fuze Mk 135 Mod 2, unarmed.

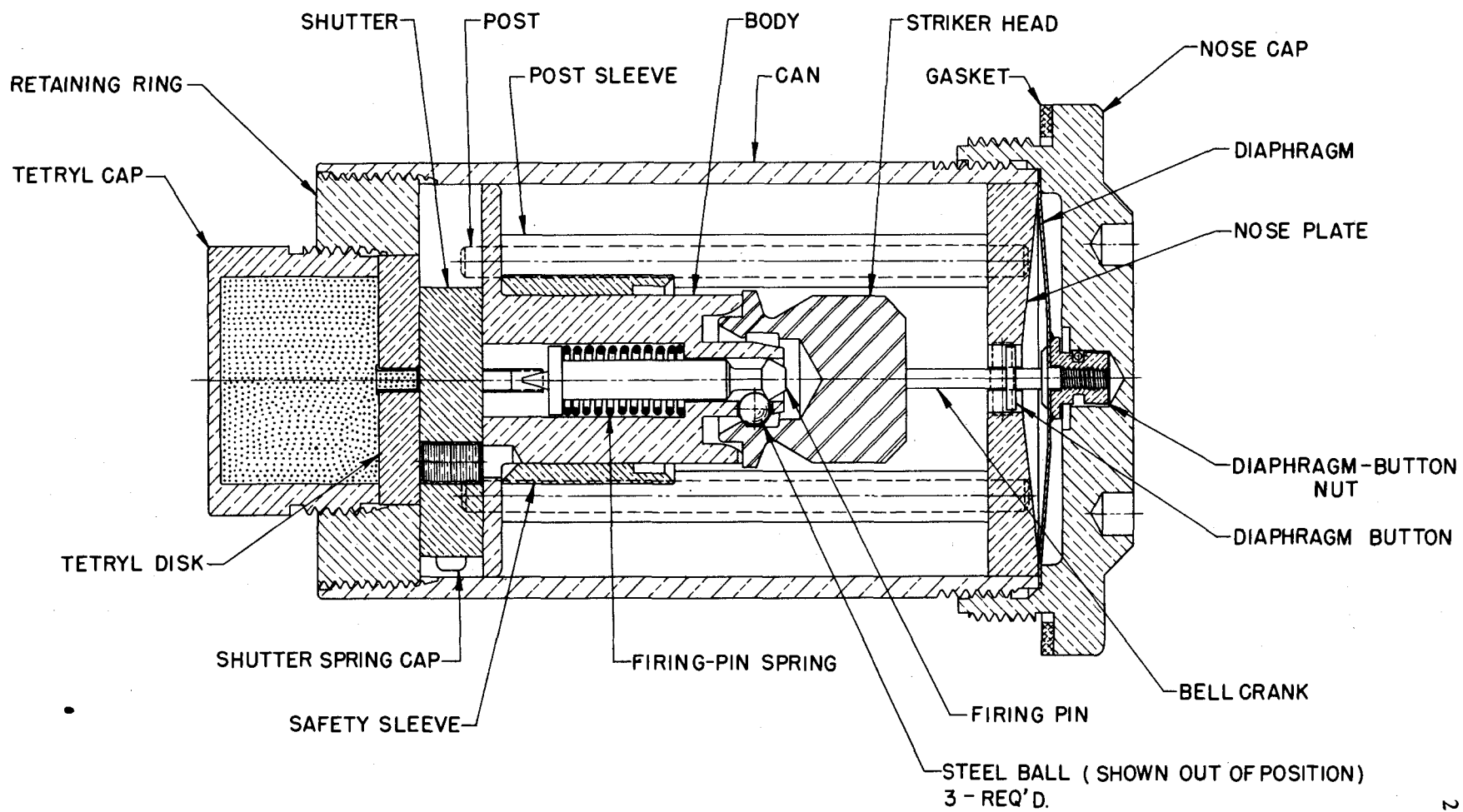
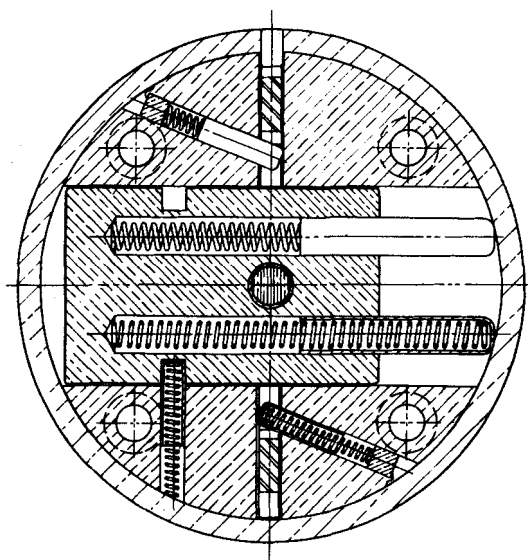


FIG. 97. Nose Fuze Mk 135 Mod 2, unarmed, turned 90° from Fig. 96.



SECTION X - X

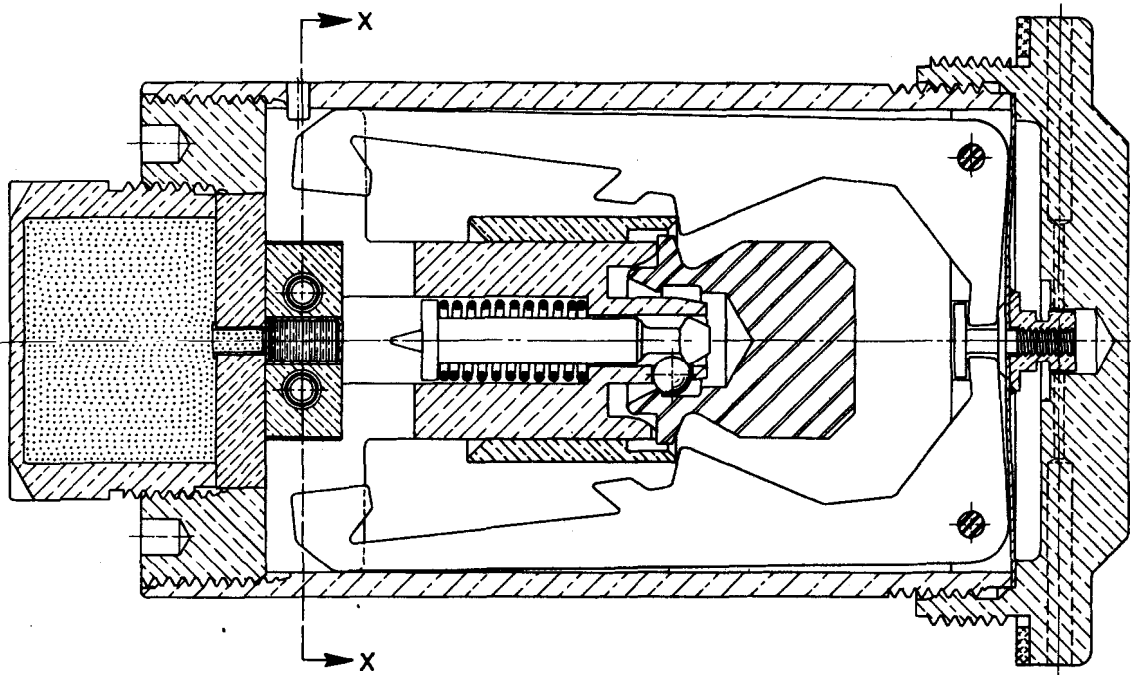


FIG. 98. Nose Fuze Mk 135 Mod 2, armed.

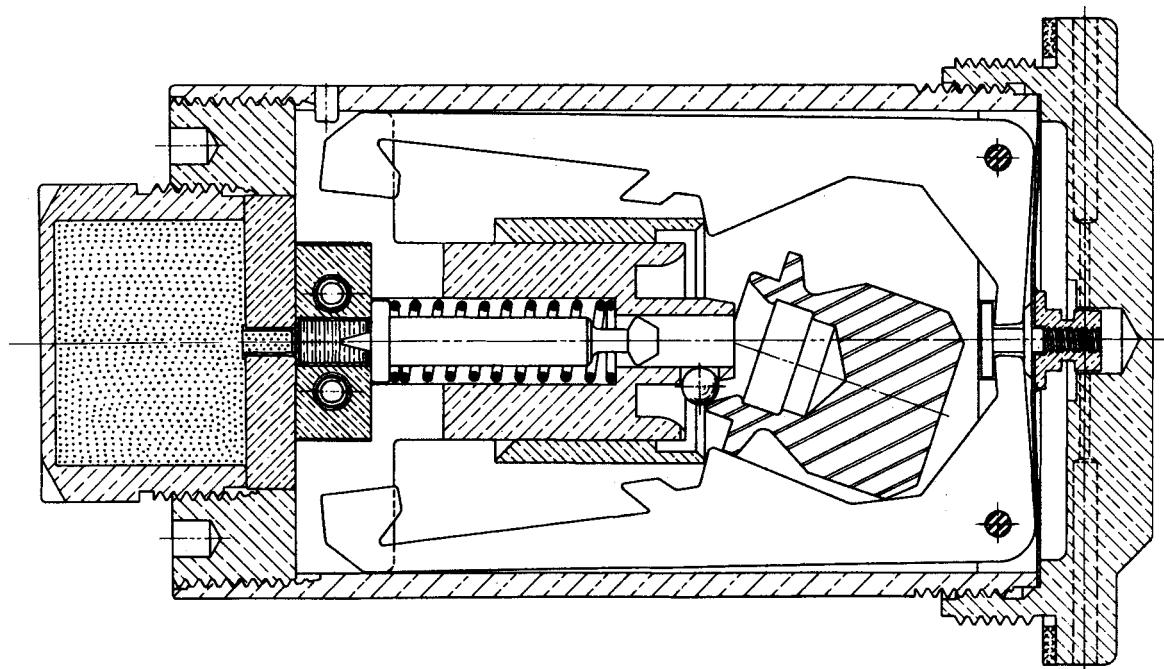


FIG. 99. Nose Fuze Mk 135 Mod 2, fired.

acts as a port cleaning device, to be inserted through the nose cap, engaging the button nut and maintaining the fuze in the *safe* position. The nose cap, which also carries the fuze mounting threads, is provided with a gasket intended as a watertight seal against the fuze liner. A retaining ring in the fuze base forces the assembly tightly against the nose cap so that deceleration forces are transmitted with only slight loss to the striker head, and serves to position the tetryl disk and retain the tetryl cap.

7.013. SAFETY.—The fuze is detonator-safe, since in the *unarmed* position the detonator is out of alignment with the tetryl lead. If the detonator should be fired accidentally in an unarmed fuze, the explosion would be dissipated harmlessly through the vent hole in the body toward the fuze interior.

The brass safety wire affords adequate protection against arming in shipping and ordinary handling, as demonstrated in the standard jolt-and-jumble tests. A pressure of about 90 lb/in.², equivalent to a depth of about 200 ft of water, is required to arm the fuze with the safety wire in place, providing a satisfactory degree of safety against pressure peaks accidentally applied. With the safety wire removed, the restoring force of the diaphragm is about 35 lb, and the fuze is safe against jolts incident to ordinary handling, since the bell cranks retain the striker head and shutter securely in place. Because of bell-crank symmetry sidewise blows which may tend to move one crank outward simultaneously urge the other inward; this action is assisted also by the interlocking action of the diaphragm button, which prevents independent crank motion. However, when loaded in a standard 60-lb round and dropped nose-down on heavy steel plate the fuze is unsafe either with or without the safety wire. At drop heights of only a few feet, the brass nose cap crushes inward, carrying the diaphragm button nut with it and usually arming the fuze, which then fires either on the original impact or that following the initial rebound.

7.014. ARMING.—Removal of the safety wire when the assembled round is placed on the launcher leaves the fuze dependent on its own internal mechanism to overcome forces tending to arm the fuze prematurely before the correct underwater depth is reached. Hedgehog motors impart an acceleration of several hundred g, which, acting on the effective mass of the diaphragm assembly and bell cranks, tends to arm the fuze. At an acceleration of 500 g the arming force amounts to about 25 lb, but the bell cranks are prevented from swinging outward both by the restoring force of the diaphragm and by the action of the safety sleeve, which during forward acceleration engages the crank hooks near the shutter. The sleeve restraining force alone amounts to about 160 lb at 500 g, providing a 6-to-1 margin of safety against arming. Since the inertia forces involved are proportional to the value of acceleration, the fuze is safe against arming at any acceleration with the same margin.

Photographic measurements have shown that the rocket-propelled projectiles in which this fuze is used rotate at about 250 rev/min at the end of normal air flight, owing to the 10° pitch of the motor tail fins. The location of the center of gravity and the lever-arm ratio of the bell cranks provide a torque tending to arm the fuze as it is rotated on its axis, offset only by the restoring force of the diaphragm. The spin arming force effective at the diaphragm button amounts to

only 0.12 lb at 250 rev/min, which is negligible in comparison with the diaphragm restoring force of 35 lb.

As the round enters the water a deceleration is sustained, tapering from a high peak at the instant of impact to a low value after a short distance of underwater travel. The dynamic water pressure wave at the ports of the fuze follows the deceleration curve and forces the diaphragm inward much earlier than if the round had been only dropped into the water. If the diaphragm action occurs too soon after water entry the fuze would "premature" (that is, fire prematurely), since the rocket deceleration would be higher than the minimum value required to force the striker head past the locking balls. Prematuring is avoided, however, both by the time required to operate the diaphragm and bell cranks and by the action of the safety sleeve in temporarily increasing the arming pressure. Water impact and the ensuing underwater deceleration drive the sleeve forward, engaging the pair of crank hooks adjacent to the striker head, thereby increasing the pressure required to operate the diaphragm by about 5 lb/in.² at a 40-g deceleration. As the round attains greater underwater depth where the deceleration is less, the diaphragm operates the bell cranks, freeing the shutter and striker head. The shutter then slides to its *armed* position, driven by the shutter springs and locked by the detent, fully arming the fuze at a depth of about 15 ft usually with the Mod 2 design in an ASR round entering the water at a 45° angle.

Prematures which may take place with this type of fuze at higher than normal entry velocity will be of the "dud" type, with the firing pin striking the shutter at a point remote from the detonator. There are two reasons for this: first, the striker head is released by the bell cranks prior to the release of the shutter, and second, deceleration presses the heavy shutter against the body recess so that the frictional force exceeds the total driving force of the two long shutter springs, which have a low spring rate. That the observed prematures have been invariably of the dud type is a great advantage in preventing the countermining of an entire salvo by the malfunctioning of a single fuze, but it is also true that the absence of surface explosions led at one time to the erroneous conclusion among personnel using the fuze that no prematures occurred, even at very high entry velocity, in rounds fired from airplanes.

7.015. FIRING.—The striker head is normally retained in position on top of the fuze body by a component of the firing-spring compression acting through (1) the firing-pin head, (2) the locking balls, and (3) the interior surface of the striker head. A sufficiently heavy impact on either the nose or side of an armed fuze, or the round in which the fuze is mounted, will permit the striker head to escape past the balls, releasing the firing pin. To prevent a series of successive small shocks from firing the fuze a restoring force, derived from the lifting of the firing pin and further compression of the spring, is effective until the head is separated from the body by approximately 0.06 in., snapping the striker head back into its original position if the deceleration is less than that required for actual firing. Upon sufficiently heavy nose impact of an armed round with a solid object, the deceleration moves the striker head forward, forcing the locking balls inward to the firing-pin neck and allowing the head to escape. The locking balls are ejected by the firing pin, which is then driven into the detonator by the compressed spring. A glancing

impact of the round causes the weight to rock on a point on the base where it is supported by the body, releasing the locking balls and firing the fuze. An independent adjustment of nose-on and sidewise fuze sensitivities is afforded in the design by moving the center of gravity of the striker head forward with respect to the base where it is supported by the body. About equal sensitivities have been found to give satisfactory performance, the fuzes firing when rounds dropping at terminal velocity contact a $\frac{1}{4}$ -in. steel plate set at 75° from normal incidence. For several reasons, one of which is to avoid interference with echo-ranging equipment, the fuzes of rounds which miss the target and drop to the bottom should not fire. The Mod 2 fuzes will not fire on a muddy bottom but will usually fire on hard-packed sand.

7.016. DEVELOPMENT OF FUZE.—As larger numbers of the Mk 135 became available from production, a series of underwater tests were made to determine in greater detail the performance to be expected in service use. Since the least settled question about the fuze was its firing sensitivity, which also governs the minimum arming depth because of prematuring, tests were made on the replica of a submarine deck, previously described. The fuzes were mounted in standard 7.2-in. ASR rounds inert-weighted to 60 lb in air, and dropped from just under the water surface onto the deck target submerged to 60 ft, where the projectile had attained its terminal velocity of about 23 ft/sec. Note was made of the position of impact, damage to the battens, and fuze functioning.

The results of about 90 drops showed that the standard Mk 135 fuze, requiring a 6-in. drop on a wooden block to fire, would consistently fire on all impacts centering less than 4 in. from a support edge, and occasionally at greater distances; also, while the battens were broken in nearly every case, the bomb did not go through. Thus, a band somewhat less than 4 in. wide on each side of the support, plus the width of the support itself, could be considered effective; this made up roughly 40 per cent of the total deck area. From the drawings of the *Graf* it was estimated that of the total projected area of 2800 ft², about 2300 ft² represented surfaces inclined less than 75° to the horizontal. Of this area about 1250 ft² was decked over, excluding the conning tower and projected area of the deck gun. Fuze firing was therefore confined to an area of 40 per cent of 1250 ft² or 500 ft² plus (2300 — 1250) ft² (assuming 100 per cent fuze functioning on all nondecked surfaces inclined less than 75° to the horizontal), or a total of 1550 ft². Thus, of the rounds which fell within the 2800 ft² total projected area of the submarine, only about 55 per cent functioning would be obtained.

A lengthy series of tests were then made to determine how the fuze sensitivity could be increased to yield 100 per cent functioning on the target but without prematuring at normal entry velocity, with a minimum number of changes in manufacture. In the course of this investigation the method of estimating fuze sensitivity was changed from dropping the fuze nose-down on a hardwood block, as well as measuring the force required to remove the striker head, to the more reproducible procedure of clamping the fuze in a hemispherical steel cap and dropping the assembly onto a massive steel block. By means of a simple release mechanism the drop height could be increased in 0.125-in. increments until firing occurred. This method was used very successfully and was found to afford a close

correlation with results obtained when the fuzes were dropped onto the batten deck under water. The original Mk 135 fuze required a drop of 3 to 4 in. on the steel block for firing. By reducing the firing spring tension from 15 lb to 12 lb and increasing the angle under the firing-pin head from 45° to 60°, measured from the pin axis, the sensitivity was increased so that drops of only 1.25 in. to 1.5 in. were required to fire the fuze. Prematuring tests disclosed that this sensitivity yielded entirely too high a percentage of prematures, however; therefore, as the simplest of several alternatives, the diaphragms were modified to increase the range of arming pressure from the originally specified 10 to 15 lb/in.² up to 17 to 22 lb/in.² This change resulted in only about 4 per cent prematures among the 1.25-in. sensitivity fuzes at the higher-than-normal entry velocity of 190 ft/sec, while none was encountered in tests at 175 ft/sec entry. This was considered an acceptable figure, especially since all prematures were of the dud type, and only a very few rounds would attain an entry velocity of 190 ft/sec in service use. The modified fuze was designated Mk 135 Mod 1 and when completed superseded production of the Mk 135. However, in order to improve the fuze immediately, a few hundred Mod 1 fuzes with a drop sensitivity of 1.5 in. to 2 in. were produced as an interim measure until the optimum sensitivity requirements could be more accurately determined for the final design. Extensive tests disclosed that 1.62 in. was the upper drop-test limit to give 100 per cent firing in the span center of the batten deck at a terminal velocity of 23 ft/sec.

As further experience was accumulated on the Mk 135 Mod 1, two additional changes were incorporated and the fuzes designated Mk 135 Mod 2. The first, intended to simplify manufacture, consisted in turning a narrow groove in the diaphragm button nut for the safety wire, and drilling the port holes in the nose cap off center. This procedure eliminated the necessity for (1) drilling the safety-wire hole through the button nut at assembly, (2) disassembling the nose cap to remove the drill chips, and (3) reassembly of the nose cap and diaphragm, which required preserving simultaneously the hole alignment and pressure seal around the diaphragm. The second change corrected an arming defect observed in laboratory tests, namely, that upon partial release of the arming pressure some of the new stiff diaphragms used in the Mod 1 would not remain snapped in the fully *armed* position with the bell cranks out against the fuze can, but would return to the *unarmed* position, pulling the bell cranks inward against the shutter. With the cranks in this position the fuze would not fire on impact, since the striker head was prevented from escaping; this behavior was very undesirable, since it meant that between the depth at which the fuze armed in the dynamic pressure wave and the depth (39 to 51 ft) corresponding to a static pressure great enough to force the bell cranks out against the can again, the fuze would be a dud. For safety reasons it was undesirable to reduce the striker head skirt diameter or alter the bell cranks. The defect was overcome by introducing two detents, of the same type as used in the shutter, into the fuze body to lock the bell cranks in the fully *armed* position.

Manufacture of fuzes within the apparently close sensitivity tolerances of 1.25 to 1.5-in. drop, was not so difficult as anticipated, even though the specifications were written to include the requirement that the firing sensitivity distribution curve of fuze production must show a maximum at 1.37 in. Once the correct

firing-spring force was determined practically no rejects were encountered; however, the fuze tolerances were not especially severe. Occasional slight production drifts away from the 1.37-in. median were compensated by using somewhat heavier or lighter firing springs. Production of fuzes meeting the sensitivity requirements was facilitated by making a subassembly of a body, striker head, firing pin, firing spring, and the three balls, mounting the subassembly in a special steel dropping fixture having a hemispherical nose, and determining the drop required to fire. If the sensitivity was outside the tolerances the parts were rejected before assembly into a complete fuze. The purpose of the clause stipulating a 1.37-in. peak in the sensitivity distribution curve was to prevent the possibility of producing all the fuzes at either the upper or lower limits, with possible increases in prematures or firing failures in service use.

7.017. REMARKS: EFFECT OF LOW TEMPERATURE ON FIRING SENSITIVITY.—The standard procedure in assembling HIR fuzes was to coat the friction-sensitive firing surfaces comprising the firing-pin head, locking balls, and striker-head interior with grease to avoid corrosion. The grease used, "Calol 0," was of a lime base composition having a melting point of 195°F, an ASTM penetration at 77°F of 310 to 340 (unworked), and a pour test of -25°F on mineral oil. Since the viscosity of ordinary greases increases rapidly as the temperature is lowered, an investigation was made of possible adverse effects on fuze sensitivity. At usual temperatures numerous previous tests had shown that the grease had only a slight effect, amounting to less than the uncertainty in establishing the exact fuze sensitivity due to variations in friction. A group of 20 new Mk 135 Mod 2 fuzes were selected for test at ambient temperatures and at 0°F with three different kinds of grease, as well as with the operating surfaces entirely free of grease. In addition to the Calol 0, Texaco cup grease No. 5 and bearing grease, Navy Ordnance Specification 1350, were tested, the latter two having been recommended by the Bureau of Ordnance for this specific application.

Laboratory tests of the effects of low temperatures were made previous to actual target drops at Morris Dam. At room temperature the 20 fuzes gave an average steel-block drop sensitivity of 1.3 in. when entirely free from grease, and 1.4 in. with the three greases. At 0°F, however, the clean fuzes required an average drop of 1.7 in. to fire, compared with 3.1 in. for the Calol 0 and Texaco No. 5, and 1.9 in. for the Specification 1350. These data indicated that difficulties could be expected in deck tests of fuzes assembled with the first two types of grease, while the Specification 1350 grease and the clean fuzes might show some failures near the span center. As a further laboratory determination the force required to remove the striker heads was measured, but no appreciable increase over the room temperature values was found with the fuzes either greased or clean. This indicated that the duration of application of the firing force was important, suggesting the possibility that the underwater deck performance might deviate from the laboratory conclusions, since the duration of impact would be intermediate between the two types of laboratory measurement.

The first step in the underwater deck tests was to determine the temperature of the fuze-firing mechanism at the instant of target impact. This was done by attaching a calibrated thermocouple to the body of an otherwise standard fuze at a

point between two locking-ball holes, setting up a test routine with a definite time interval for each step, and establishing the fuze warming curve while following the timed routine. An increase of only 4°F above the refrigerator temperature was encountered by the time the rounds carrying the fuzes reached the underwater target submerged to 60 ft, at the prevailing lake and air temperatures.

The results of the target drops showed an interesting deviation from the laboratory tests. The fuzes assembled with Calol 0 fired in a pattern only slightly better than the original Mk 135, failures starting at a distance of no more than 6 in. from a support. Contrary to the laboratory block drop tests, the Specification 1350 grease gave even poorer results, with failures beginning at 4.5 in. from a support, while the Texaco cup grease No. 5 yielded the worst results, with not a single fuze firing, even though two struck directly on the heavy steel deck supports. The fuzes assembled without grease performed as well at 0°F as at normal temperatures, all fuzes firing in a total of 30 drops, including 16 which struck within 2 in. or less of the span center. The deck tests proved conclusively the necessity for assembling inertia-firing fuzes free from grease for sensitivity reasons; an additional reason is the fact that grease and oil cause deterioration of the fuze explosive components.

7.018. REMARKS: NOTES ON PREMATURING.—Only a relatively few tests were made in an effort to discover more about the prematuring characteristics of the Mk 135 fuze, since it was already being replaced by the smaller and less expensive Mks 131 and 136, and the expected successor to all three fuzes, the Mk 140, was in the pilot production stage.

The prematuring problem, as noted above, became especially troublesome when the fuze sensitivity was increased for the Mk 135 Mod 1 and Mod 2 fuzes. The point most frequently observed was that prematures appeared in a highly erratic manner and could not be related to any of the quantities normally measured in the course of production. For example, in one test made at an entry velocity of 190 ft/sec, involving 30 different fuzes with drop sensitivity ranging from 1 in. to 1.25 in., arming pressure from 17 to 22 lb/in.², and force required to remove the striker heads from 7 to 11 lb, two dud prematures occurred. One of the prematuring fuzes had a sensitivity of 1.25 in., an arming pressure of 19 lb/in.², and a head-removal force of 9 lb, while the other measured 1.25 in., 20 lb/in.², and 10 lb respectively. In the group four other fuzes which did not premature possessed characteristics more favorable to prematuring, having drop sensitivities of only 1 in., arming pressures of 19, 20, 21, and 22 lb/in.², and head-removal forces of one at 8 lb and three at 9 lb. Numerous other fuzes in the group having 1.25-in. sensitivity showed both lower striker-head-removal force and arming pressure of only 17 lb/in.² The two fuzes which had prematured were reassembled and fired again three times each, with no premature occurring. Orientation of entry ports with respect to the water surface at the instant of entry did not appear to be of significance in prematuring.

Another series of tests were made using a group of 20 new Mod 2 fuzes selected for combined maximum drop sensitivity of 1.25 in. and minimum arming pressure of 17 lb/in.² No prematures were encountered at 195 ft/sec entry. Five of the reassembled fuzes were fired at 250 ft/sec velocity in 58-lb rounds without pre-

maturing. Neither of two fuzes that were fired at 270 ft/sec in 66-lb rounds prematured. At 300 ft/sec one premature in three fuzes occurred with a 60-lb round, and two out of six fuzes prematured with a 68-lb round.

The increase in arming pressure to the range of 17 to 22 lb/in.² to avoid pre-maturing in the Mod 1 and 2 fuzes was not an altogether satisfactory solution. A group of 19 fuzes, selected for the maximum permitted arming pressure of 22 lb/in.², were fired at 175 ft/sec into a net target submerged 25 ft. Four of the fuzes failed to arm at that depth, indicating that during the dynamic pressure wave the peak pressure over the diaphragm did not reach the value required to arm the fuze. In service use, however, the fuzes presumably would have armed later when the static pressure built up, at a depth of about 51 ft. At somewhat higher entry velocity all fuzes would have armed in the dynamic pressure wave, while at the Hedgehog entry of 140 ft/sec it is probable that none of these fuzes would have armed at less than 51 ft.

7.019. PRESENT STATUS.—The manufacture of this fuze was abandoned after approximately 25,000 had been produced, as it was to be replaced by the smaller pressure-arming fuze, the Mk 140. The Mk 135 and mods are now listed as obsolete.

7.02. MK 139 FUZE

Rockets in which used (retro-bombing)

7.2-in. Rocket Mk 11, with 3.25-in. Motor Mk 1 (Mk 6 grain) and 7.2-in. Head Mk 6. Total nominal weight of rocket, 65 lb; nominal entry velocity, 200 ft/sec.

7.2-in. Rocket Mk 12, with 3.25-in. Motor Mk 2 (Mk 7 grain) and 7.2-in. Head Mk 6. Total weight of rocket, 68 lb; entry velocity, 300 ft/sec.

7.2-in. Rocket Mk 13, with 3.25-in. Motor Mk 3 (Mk 8 grain) and 7.2-in. Head Mk 6. Total weight of rocket, 71 lb; entry velocity, 400 ft/sec.

7.2-in. Rocket Mk 14, with 3.25-in. Motor Mk 4 (Mk 9 grain) and 7.2-in. Head Mk 5. Total weight of rocket, 62 lb; entry velocity, 200 ft/sec.

Dimensions and weight

The over-all dimensions, weight, and mounting-thread details are given in the outline drawing (Fig. 100).

Materials

Materials used for essential parts are brass alloy casting for the body, steel for the firing pin, clamp, cap, and arming spring, brass rod for the plate, set-back collar, closure disk, shutter, and lead-in disk, and die-casting alloy for the magazine. The firing wheel is die-cast of manganese bronze. The cap gasket is made of red flexible fiber.

Explosive components

Detonator: instantaneous

Lead-in: tetryl

Booster: tetryl

General arrangement drawing

BuOrd Drawing No. 375593

7.021. GENERAL.—The Mk 139 fuze, designated originally as the SIR, is a spring-arming, point-detonating fuze used with rocket ammunition. It was designed primarily for retro-bombing in antisubmarine warfare, intended for use in rounds which are fired rearward from a low-flying aircraft by rocket motors at a velocity substantially equal to the forward speed of the airplane. Since the rocket flight under these conditions tends to be somewhat unstable, the fuze must be designed to arm reliably regardless of whether the round is falling nose-down or sidewise. For safety reasons arming must be delayed for a short but uniform time after the round leaves the airplane. As retro-bombing was intended to be useful against surfaced as well as completely submerged submarines, fuze firing was required to be not only water-discriminating at high entry velocity but also sensitive to contact on either a submarine wooden deck or inclined steel hull surfaces, at velocities down to the 24 ft/sec underwater terminal speed of the rounds. Since air-arming vanes were not adaptable to this application, a coiled spring was used as the source of arming energy, combined with a flywheel to afford an appreciable time delay. As the water-discriminating requirement ruled out simple forms of inertia-firing devices, the fuze was made point-detonating with the minimum firing sensitivity that would permit consistent functioning on a slat deck at ter-

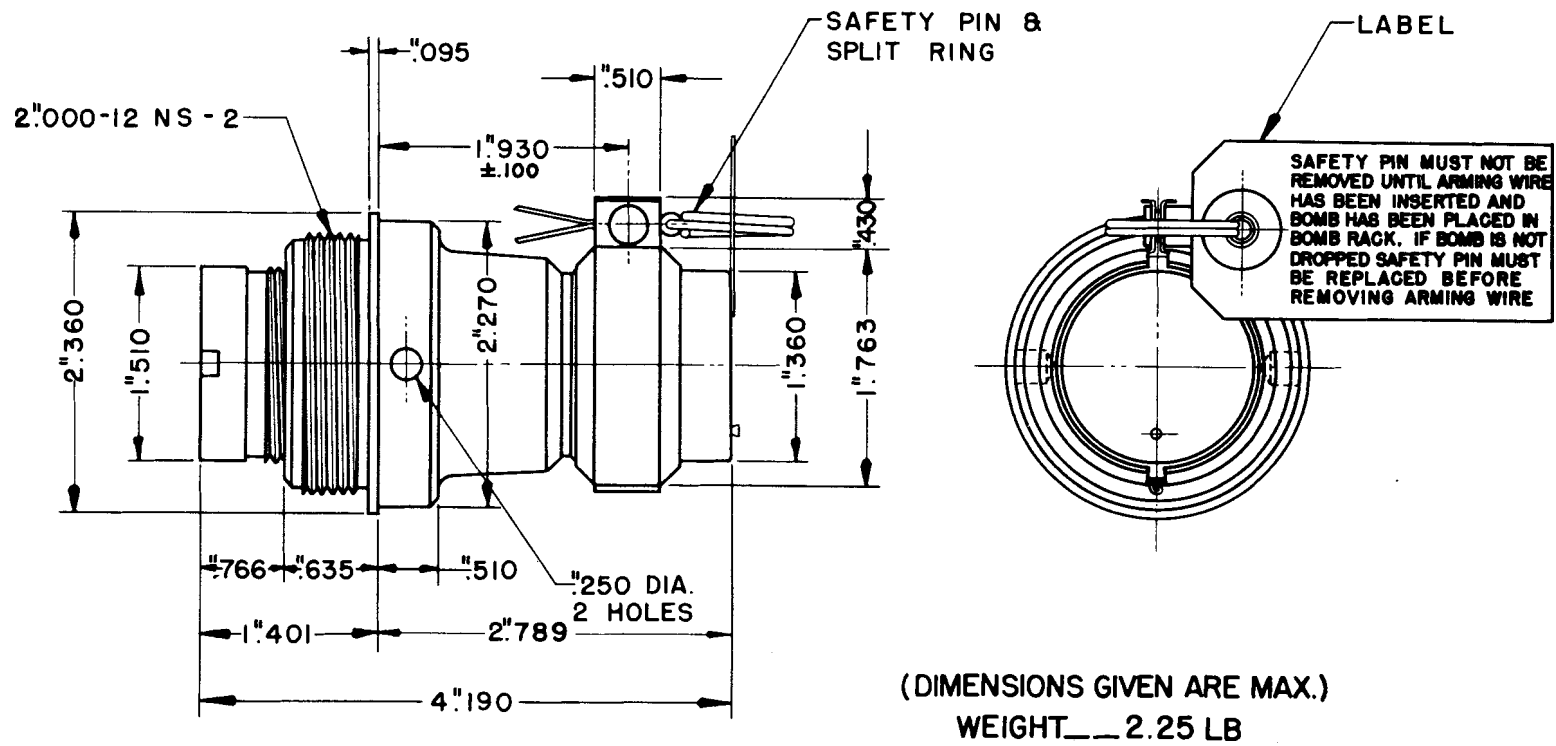


Fig. 100. Outline view of Nose Fuze Mk 139 Mod 0 (SIR).

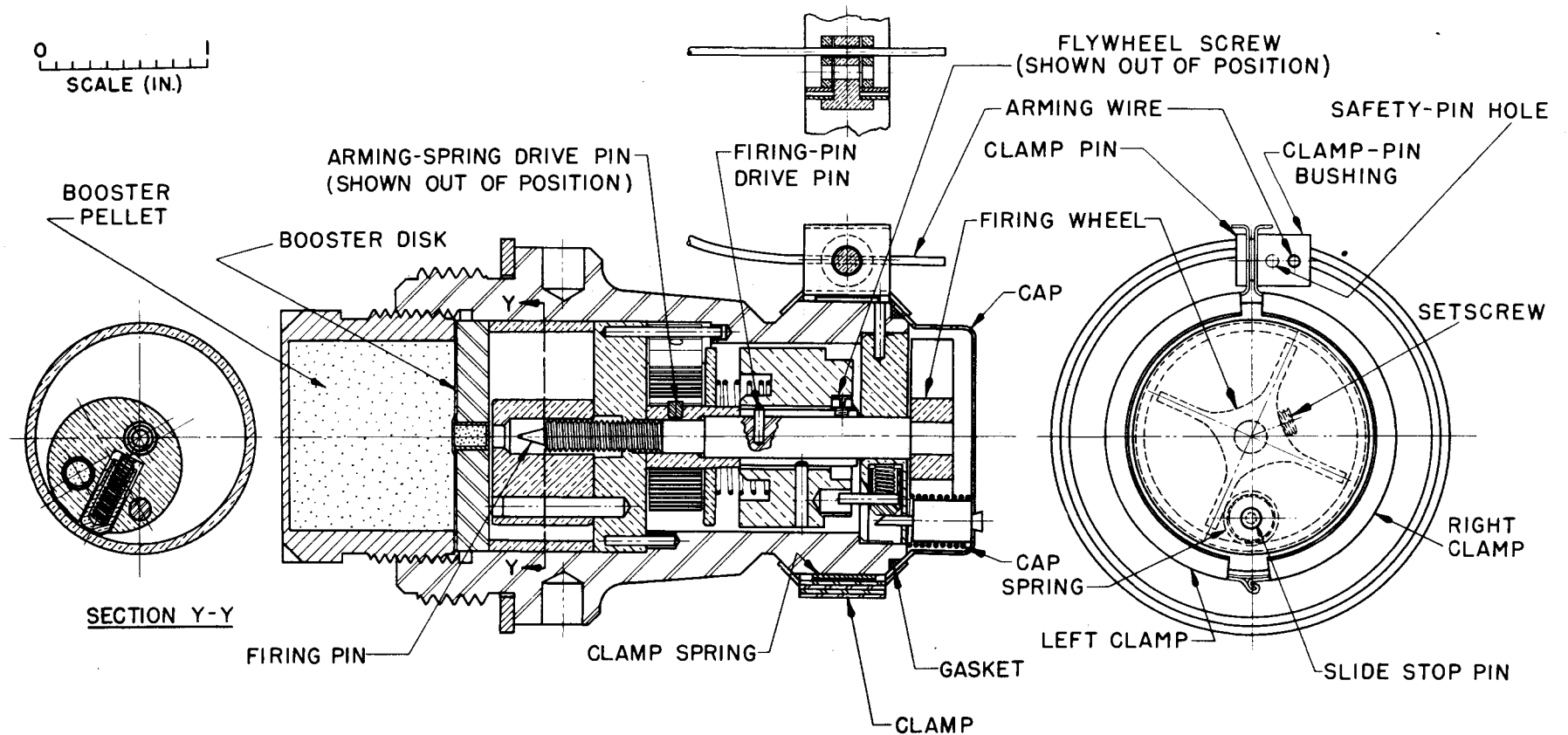


FIG. 101. Nose Fuze Mk 139 Mod 0, unarmed.

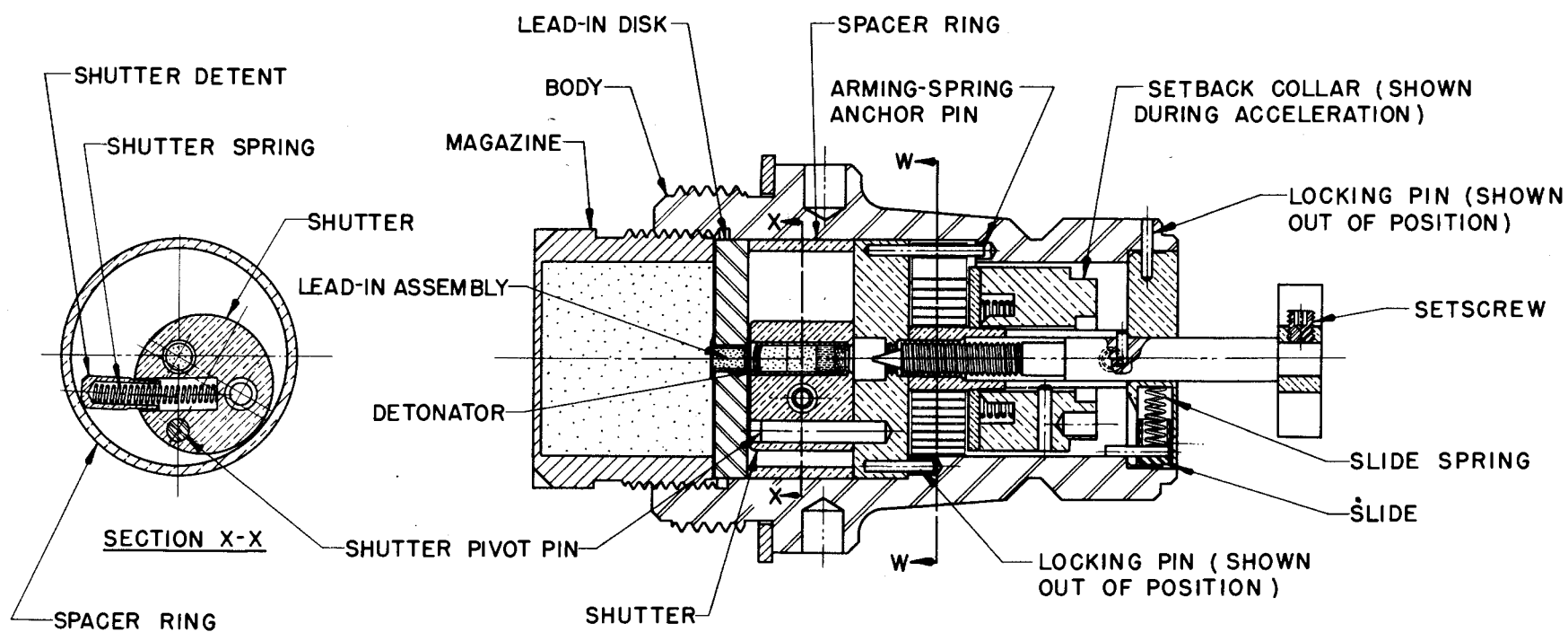


FIG. 102. Nose Fuze Mk 139 Mod 0, armed.

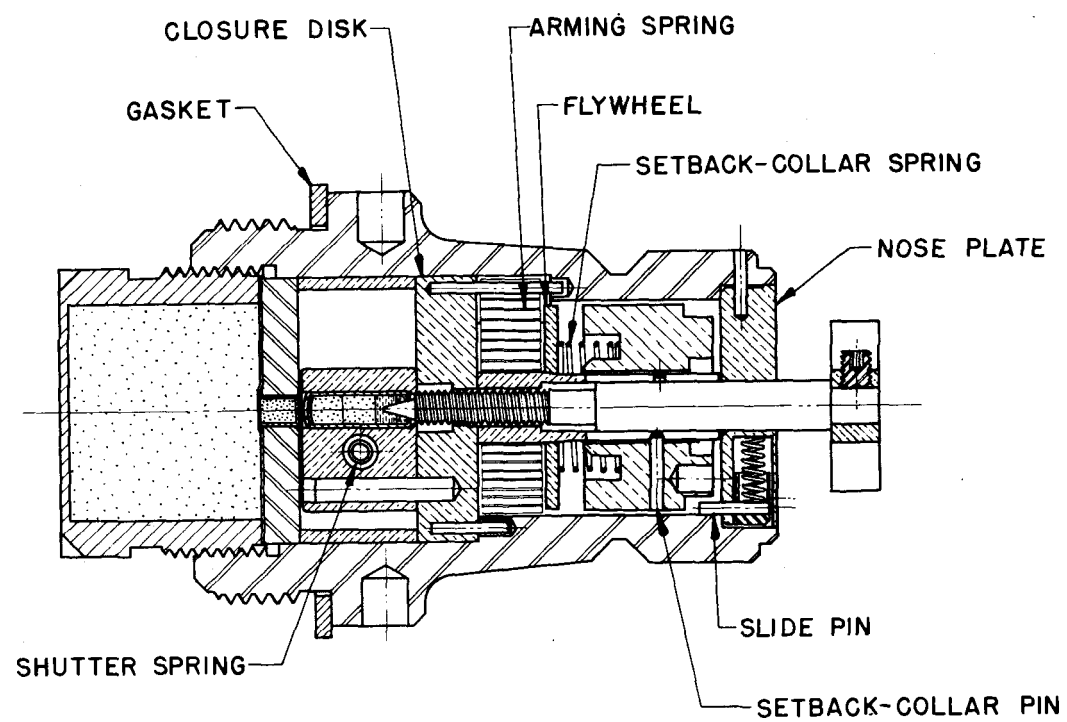


FIG. 103. Nose Fuze Mk 139 Mod 0, fired.

minal velocity, and with the maximum external contact area of the firing pin that would avoid prematuring upon water impact at the highest entry velocity contemplated. Since the fuze was to be carried on aircraft, effective protection against moisture and icing was necessary.

7.022. MECHANICAL DESIGN.—The essential fuze mechanism is designed around a threaded firing pin which can be unscrewed forward through a large nut by means of an arming spring connected to a time delay element. When the pin moves forward a shutter is released into an *armed* position, and a firing wheel is extended ahead of the fuze body; this wheel is attached to the end of the firing pin in order to increase the otherwise small contact area of the pin. Firing is effected upon a sufficiently heavy impact of the wheel with a solid object, which forces the projecting firing pin backward, shearing the nut threads and penetrating the detonator.

The time delay device, driven directly by the arming spring, acts as a simple inertia element and consists of two parts, the flywheel and setback collar. The latter is mounted loosely on the flywheel hub, free to move backward under restraint of the setback collar compression spring, but rotated by the setback collar pin fitting into one groove of the slotted flywheel hub. The other groove of the hub is engaged by the firing-pin drive pin, and serves in arming to unscrew the firing pin from the shear threads in the closure disk.

The fuze mechanism is protected against the weather and also maintained safe by the assembly of cap, gasket, and separable clamp, which is locked together by the safety pin or arming wire. With the cap in position, the arming-spring driving torque which tends to rotate the internal mechanism is resisted only by a spoke of the firing wheel bearing against the cap spring, which surrounds the slide stop pin, and not resisted by engagement of the stop pin with the hole in the setback collar. This leaves the collar free to return to its *unarmed*, fully forward position without friction against the slide pin, if the collar should deflect backward from jolts that are incident to handling the fuze. However, a degree of safety is afforded against fuze arming in event of accidental removal of the cap, by the ensuing engagement of the slide pin with the collar hole, provided no appreciable setback forces act during or subsequent to cap removal. Under conditions of normal firing, removal of the cap with its slide stop pin is accompanied by setback; this operation frees the slide to move radially outward where the slide pin cannot interfere with the spinning setback collar if arming should be incomplete by the end of rocket acceleration.

The shutter is housed within a spacer ring which separates the closure and lead-in disks, and is retained in the *safe* position by the firing pin. A single detent-and-driving-spring assembly serves to rotate and lock the shutter in its *armed* position when the firing pin is removed during arming. By combining the shutter driving and locking functions in one spring and a specially formed cap, the thrust and resultant friction against the firing pin may be made very small and uniform.

7.023. SAFETY.—The fuze is detonator-safe, since in the *safe* position the shutter maintains the detonator out of alignment with the tetryl lead-in and over a vent hole leading to the fuze interior.

Safety against heavy impact on the fuze nose is assured by the design in which the motion necessary to arm the fuze is outward and not inward. In safety drop

tests the relatively weak forward structure of the body collapses backward, and the firing pin penetrates the tetryl lead but without initiation.

Since the fuze is armed by setback and removal of the cap, there are two holes through the clamp pin and bushing, one of which must be occupied by either the safety pin or arming wire at all times. In loading the round on an airplane the arming wire is inserted before the safety pin is removed, and in removing an unused round the safety cotter pin is inserted and the points spread before removal of the arming wire. If a fuzed round were to slip out of the launcher, pulling the arming wire through the clamp pin, and fall to the ground or carrier deck, the fuze would be moderately safe from arming in spite of the cap loss, because of the previously described engagement between the slide pin and setback collar, which is maintained in the absence of impacts on the tail of the round.

7.024. **ARMING.**—When the rocket motor is fired, acceleration forces the setback collar rearward, compressing the collar spring. The arming wire slips out of the clamp pin, unlocking the two halves of the clamp, which are forced apart by the clamp spring. The fuze cap is then ejected by the heavy compressed cap spring, releasing both the firing wheel and slide, and allowing the flywheel-and-firing-pin assembly to be rotated by the arming spring. The firing pin screws forward out of engagement with the shear threads of the closure plate, permitting the shutter to swing into the *armed* position, and extending the firing wheel ahead of the fuze body. The arming time, measured in 14 rounds fired at 205 and 300 ft/sec from an aircraft in flight, varied from 0.71 to 0.87 sec, averaging 0.77 sec. There was no significant difference in arming time of fuzes on the ammunition having the two different velocities. The corresponding mean arming distances were 29 ft below and 117 ft behind the airplane with the slow rounds, and 14 ft below and 176 ft behind with the 300-ft/sec ammunition. Since the average arming time is greater than the duration of setback for many rocket motors at ordinary temperatures, the necessity is evident for the fuze slide and spring to move the slide pin outward beyond the spinning setback collar in an early stage of arming.

For some fuze applications involving entry velocity of about 300 ft/sec it is possible that arming may not be completed at the time of water entry. A few tests have shown that at an entry velocity of 225 ft/sec an unarmed fuze without cap will not begin to arm until the round reaches a depth of at least 30 ft. Some improvement in this regard may be made by bending the spokes of the firing wheel into a radially curved form to utilize the flow of water past the fuze nose; several tests indicated that complete arming may be expected at depths of 20 ft at a 45° entry angle.

Underwater rotation of the projectiles is in a direction to cause the firing pin to be screwed back into the detonator if appreciable drag is caused by the firing-wheel spokes, but tests of the fuzes have shown that there is no apparent tendency for this action to take place; however, if encountered under unusual entry conditions, it could be corrected by curving the spokes in an opposing direction.

7.025. **GASKET TESTS.**—One of the prime requirements in the operation of the SIR fuze is that the waterproof cover must function properly by flying off when the pulling of the arming wire releases the clamp assembly. In this process the gasket that seals the cover to the body, besides being watertight, must have no

tendency to stick to the cover under any condition. Numerous tests were run on different gasket materials. The procedure was usually to soak the assembled fuze in water to test the cover assembly for leaks, then place the fuze in an oven at 170°F for at least 24 hours, and finally transfer it to a refrigerator at 0°F or lower for an equal period. The temperature cycle was reversed on other fuzes with the same type of gasket. At the end of the test run the safety wire was pulled and any tendency for the gasket to stick was noted.

Altogether, between 20 and 30 gasket materials or combinations of materials were tested. The only material found to satisfy the requirements was flexible fiber. It was found that any material containing rubber or a binder which might come out at high temperature would stick. No satisfactory surface coating for rubber gaskets was found.

7.026. FIRING.—A sufficiently heavy impact on the firing wheel, directed either straight back or at an angle giving a strong backward component, will force the threaded firing pin through the shear threads of the closure disk and into the detonator. In numerous tests made on the submarine decking inert fuzes, mounted in ASR rounds and dropped under water at a terminal velocity of 24 ft/sec, have shown reliable mechanical firing except when the firing wheel penetrates the space between battens. The shape of the fuze and associated rocket limits the angle at which firing may be expected on the slant plate to somewhat more than 45°. Tests made at the 45° angle show that detonator penetration will consistently occur if the fuzes are mounted in ASR rounds and are falling under water at a velocity of 24 ft/sec.

7.027. PREMATURE.—The length and width of firing-wheel spokes were correlated in design with the force required to shear the closure-disk threads, so as to obtain the greatest lateral extension of the firing pin for target contact with the least tendency to premature upon water impact at high entry velocity. The relations between these factors have been adjusted to avoid prematures at entry velocities up to 450 ft/sec with an entry angle of 45°.

A series of calibration tests have been made to determine the value of the impact forces sustained by the firing pin at water entry and upon contact with the decking, relative to the force required to shear the closure-disk threads. The most satisfactory procedure was to replace the detonator with a lead block and record the impression made by a flat-pointed firing pin passing through a clearance hole in the closure disk, calibrating the results by comparison with similar impressions made by dropping a 9-lb weight on the firing wheel. It was found that a 6 to 7-in. drop of the weight was required to shear the closure-disk threads, while water impact at 450 ft/sec corresponded to a 1 to 2-in. drop. The minimum deck impacts of fuzes in ASR rounds dropping at 24 ft/sec under water were equivalent to an 11-in. drop of the weight. Somewhat more than the minimum force required to shear the threads is necessary to insure detonator functioning.

7.028. PRESENT STATUS.—The fuze is considered obsolete because of the abandonment of retro-bombing.

7.03. Mk 140 FUZE

Ammunition for which designed

ROCKETS FOR SHIPBOARD USE

7.2-in. Rocket Mk 8, with 2.25-in. Rocket Motor Mk 3 and mods (except Mod 1) (Mk 3 grain) and 7.2-in. Head Mk 5, TPX-filled. Total nominal weight of rocket, 61.5 lb; nominal velocity, 175 ft/sec.

7.2-in. Rocket Mk 10. Same as Mk 8 except that it has Mk 10 grain, and is TNT-filled. Total nominal weight, 57.5 lb.

7.2-in. Rocket Mk 15. Same as Mk 8 except that it has 7.2-in. Head Mk 4, and total weight of 62.5 lb.

HEDGEHOG AMMUNITION FOR MK 10 AND MK 11 PROJECTORS,
FOR SHIPBOARD USE

7.2-in. Projector Charge Mk 6, with PC Motor Mk 6 and PC Head Mk 4 (except Mk 4A). Total nominal weight, 65 lb; TNT-filled.

7.2-in. Projector Charge Mk 7. Same as Mk 6, except filling, which is TPX. Weight, 68 lb.

Dimensions and weight

The over-all dimensions, weight, and mounting-thread details are given in the outline drawing of the Mk 140 fuze (Fig. 104).

Materials

Materials used for the essential parts are steel for the external parts (except the die-cast magazine), as well as for the internal diaphragm seat, firing sleeve, bell cranks, striker ring, safety ring, and firing pin. The shutter, head, and base are variously made of steel, brass, and Zamak die-casting alloy. The diaphragm is made from either phosphor bronze or brass. The diaphragm seat gasket is of copper.

Explosive components

Detonator: instantaneous

Lead-in: tetryl

Booster: tetryl

General arrangement drawing

BuOrd Drawing No. 375899

7.031. GENERAL.—The Mk 140 fuze, also of the pressure-arming, impact-firing type, was originally designed to duplicate the performance of the Mk 135 Mod 2 with as small and light a mechanism as practicable. It was also intended to replace the Mk 131 and 136 fuzes, which at that time were giving unsatisfactory performance and were not readily adaptable to certain new kinds of underwater contact charges in process of development.

The Mk 140 fuze was originally intended to arm at depths of less than 20 ft when used in either Hedgehog or ASR rounds, and to fire upon impact with the wooden decking of a submarine or with hull sections inclined at less than 75° from the horizontal. These requirements later were modified to permit a maximum arming depth of 50 ft and firing on a maximum inclination of 60° from horizontal.

However, the final acceptance tests showed the fuzes to be so variable in both arming and firing performance that production was halted and none was issued for service use. This action was also influenced by contemporary improvements in the much simpler Mk 131 and 136 fuzes which brought their test performance up to virtually a perfect score. The Mk 140 fuzes were placed in storage for reworking in accordance with improvements outlined later, since the versatility of a pressure-arming fuze was desired for special applications.

7.032. MECHANICAL DESIGN.—Comparison of the drawings of the Mk 140 (Figs. 104 to 108) with those of the Mk 135 Mod 2 will show the similarity in basic principles. The conically formed diaphragm is clamped between a nose cap, screwed into the upper end of the body, and a diaphragm seat, which supports the diaphragm at high pressure and also retains the internal mechanism. Two bell cranks, pivoted in the fuze head and interlocked by the diaphragm button, hold the firing sleeve and shutter in the *safe* position until the fuze is armed. The safety ring resembles the Mk 135 safety sleeve, except that it engages the bell-crank hooks only during acceleration. The firing mechanism, while of the inertia type as before, differs in that the striker head has been divided into two parts—firing sleeve and striker ring. This modification was necessary, since the head and base of the Mk 140 are connected by a column passing through the center of the fuze, rather than by the four external posts of the Mk 135, which afforded space in the center for the one-piece striker head to rock off in any direction. As the firing sleeve of the Mk 140 is able to move only parallel to the fuze axis, sidewise sensitivity is derived from the rounded striker ring, retained between smooth bevelled surfaces on the under side of the firing sleeve and on top of the base. Sidewise motion of the ring in any direction is thus translated into axial motion of the firing sleeve, while for nose-on impact the mass of the striker ring simply adds to that of the sleeve. Restoring force for the firing sleeve is obtained from the two firing-sleeve releasing springs instead of from a component of the firing-spring compression as in the Mk 135. The smooth cylindrically bored hole in the center of the firing sleeve retains two locking balls which restrain the spring-loaded firing pin. The forward end of the firing spring presses against the diaphragm button, in contrast to the unloaded diaphragm of the Mk 135, and is one of the forces determining the arming pressure. To assist in the prevention of prematures at water entry, the effect of the safety sleeve engaging the forward bell-crank hooks in the Mk 135 fuze has been replaced in the Mk 140 by a partial interlock between the cranks and the actual firing mechanism. When a round enters the water deceleration causes the firing sleeve to move forward; the lower crank hooks are then engaged by a groove in the firing sleeve, momentarily increasing the fuze arming pressure.

In the lower end of the fuze are located the shutter and conventional lead-in disk and magazine. The shutter is very similar to that of the Mk 135—a massive block driven by long coil springs of low spring rate and locked by two detents when in the *armed* position. The lead-in disk and magazine close the end of the fuze and serve to tighten the internal mechanism against the diaphragm seat so as to transmit the deceleration firing forces with little loss to the firing sleeve and striker ring. The guide pin in the body engages a bell-crank slot in the fuze base

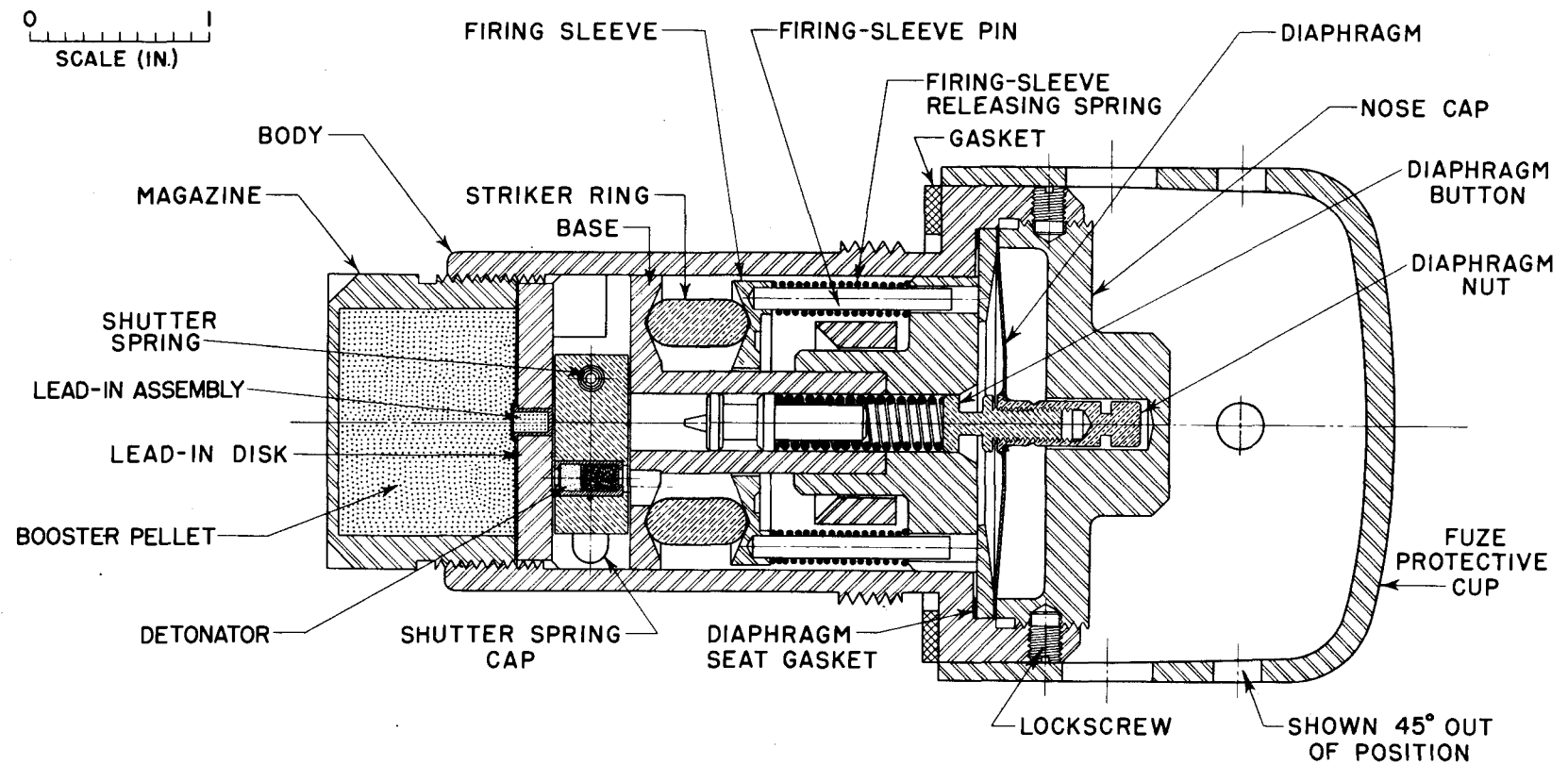


FIG. 105. Nose Fuze Mk 140, unarmed.

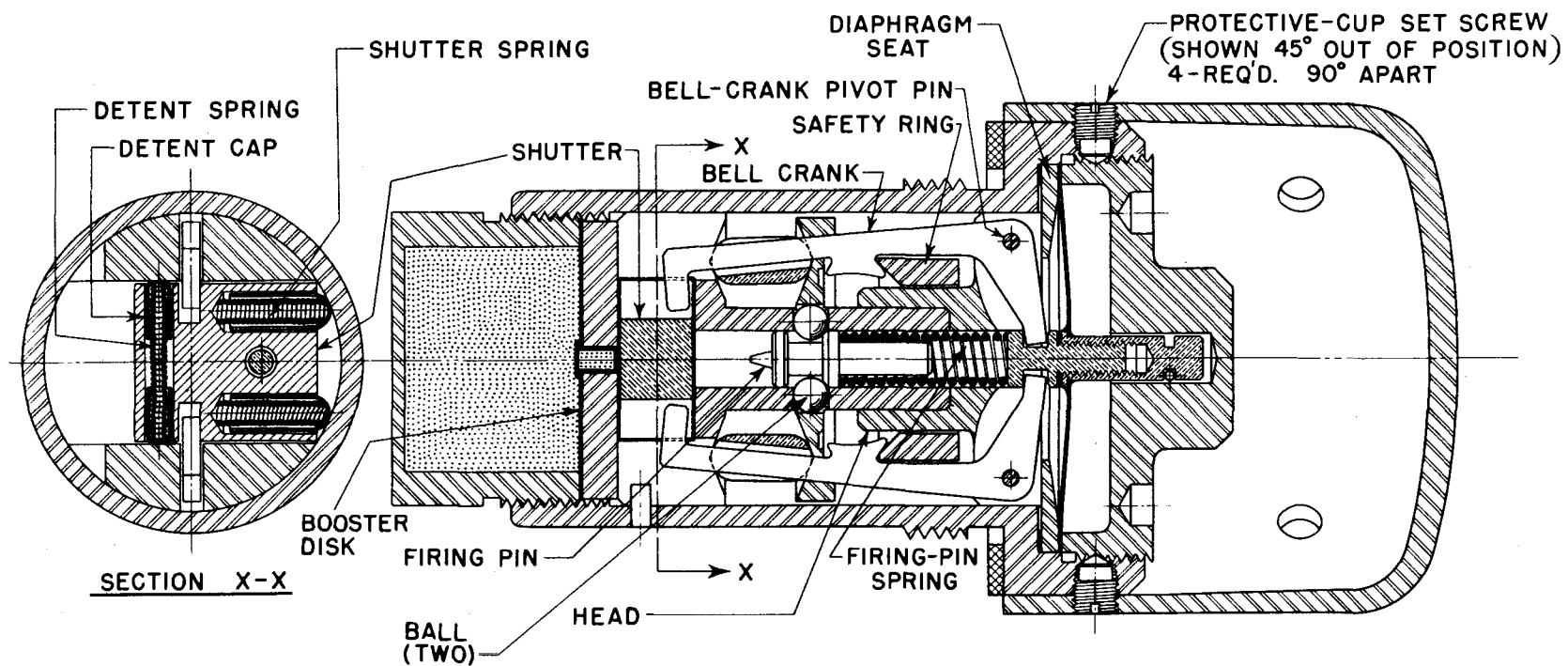


FIG. 106. Nose Fuze Mk 140, unarmed, turned 90° from Fig. 105.

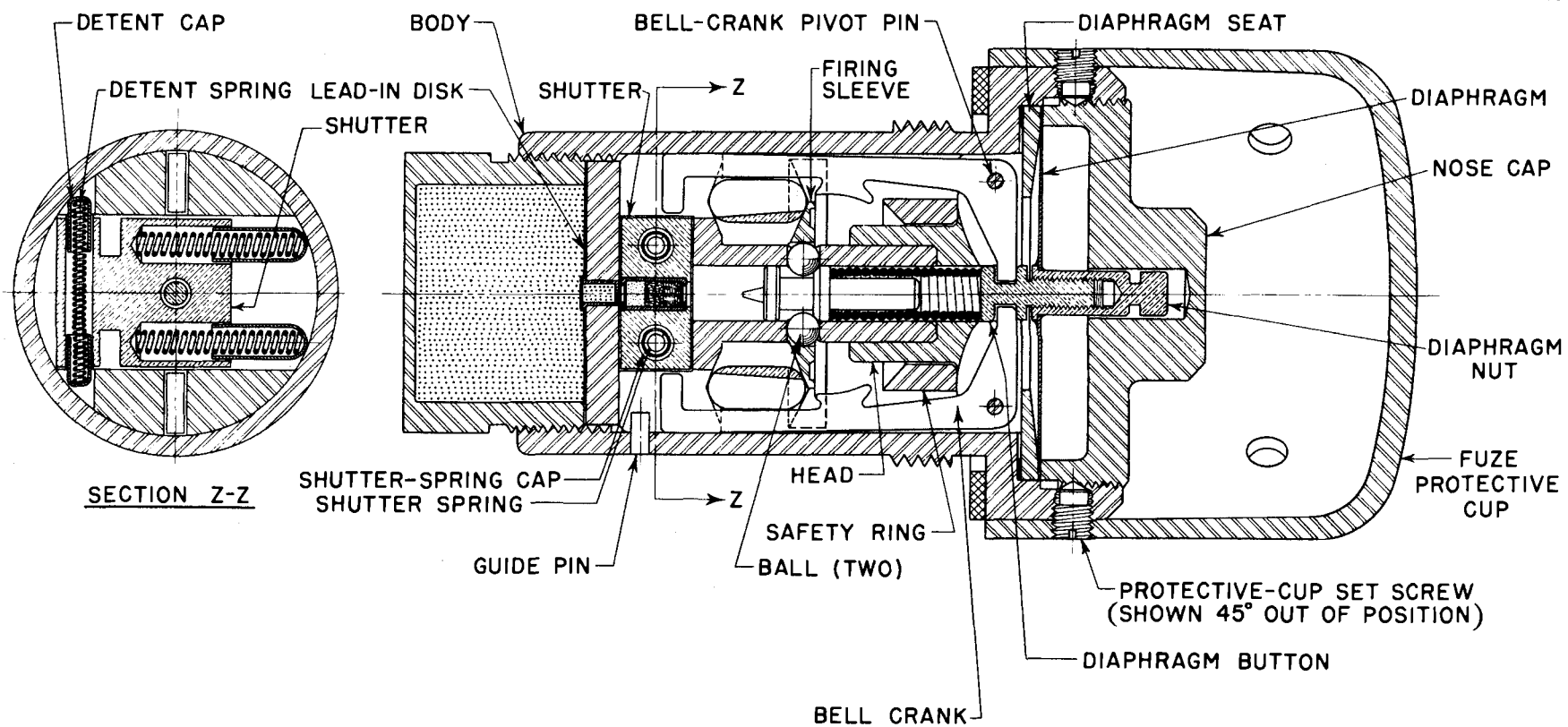


FIG. 107. Nose Fuze Mk 140, armed.

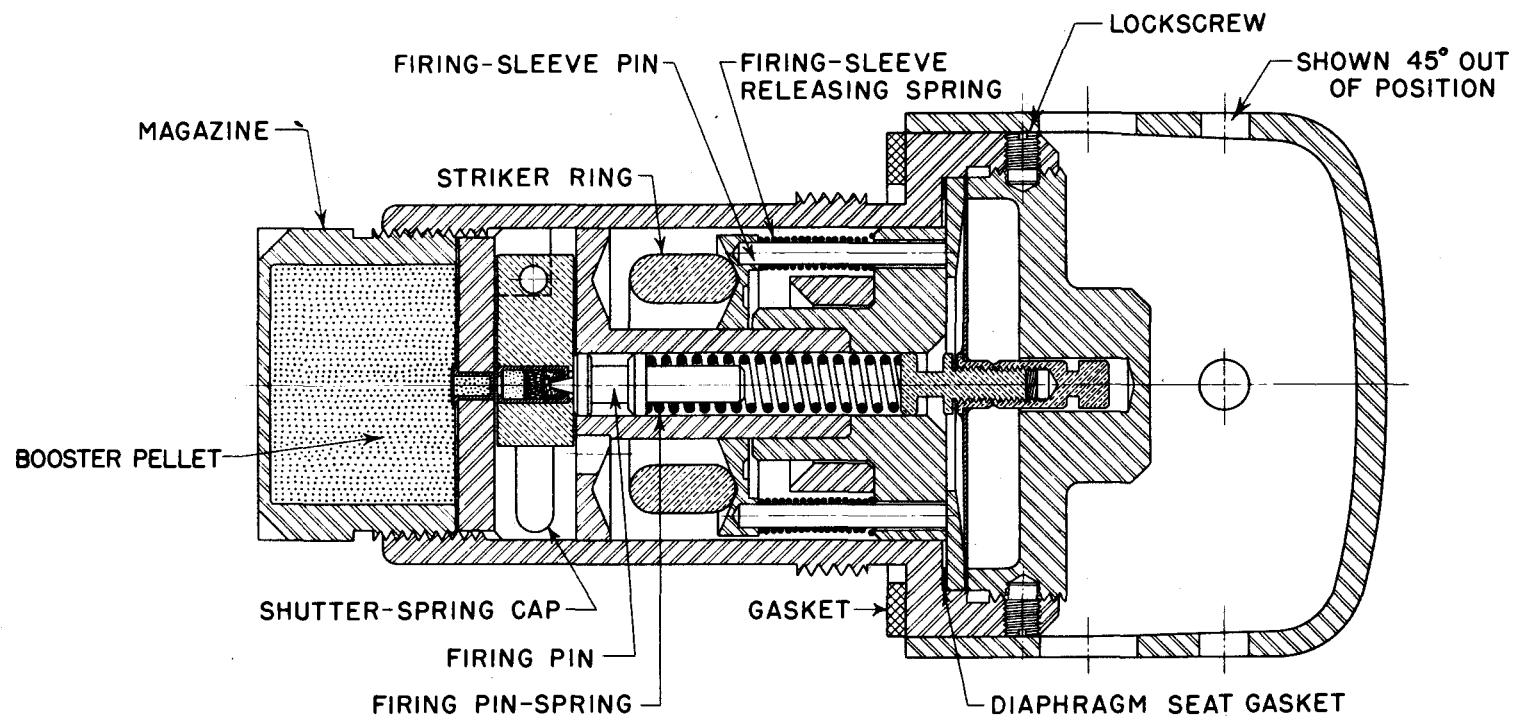


FIG. 108. Nose Fuze Mk 140, fired.

to prevent possible twisting and misalignment of the latter with respect to the head as the magazine is tightened.

The nose cap is provided with two 0.055-in. water intake ports drilled off center to allow a safety wire to engage a narrow groove turned in the diaphragm nut. The ports are counterbored a short distance with a $\frac{1}{8}$ -in. drill to facilitate entry of the safety wire. A gasket under the body external shoulder is intended as a water seal when the fuze is screwed tightly into a liner. The protective cup was added after many thousands of fuzes had been manufactured, to afford protection against arming and firing if a fuzed round were dropped accidentally in handling.

7.033. SAFETY.—The fuze is detonator-safe, since in the *unarmed* position the detonator is out of alignment with the lead-in charge, and over a vent hole in the base leading to the fuze interior.

The safety wire is effective in preventing accidental arming during transit and storage and in the course of ordinary handling. As a further safety measure and for easy detection of an armed fuze from the exterior, the dimensions and alignment of the port holes, diaphragm nut groove, and safety wire permit the wire to be passed through the nose cap only when the fuze is safe. Bell-crank symmetry and the interlocking action of the diaphragm button also assist in maintaining safety, as in the Mk 135. The safety drop-test specifications require that a fuze, assembled in a round of standard weight, be safe after dropping in any position onto armor plate from a height of 25 ft; these are more than met by the deforming action of the protective cup. The two lock screws in the fuze body prevent the possibility of unscrewing the nose cap and accidentally arming the fuze if the wrong procedure were to be used in attempting to remove a badly corroded fuze from a round.

7.034. ARMING.—The discussion under this section of the Mk 135 prototype also is applicable to the Mk 140. This fuze does not have as ample a margin of safety against Hedgehog arming as the Mk 135, however, even with the firing-spring compression aiding, since the safety ring has a smaller mass and the bell-crank lever-arm ratio is not so advantageous, but the existing margin of two to one is considered sufficient. A few tests have shown that fuzes will not arm in Hedgehog rounds even with the safety sleeve removed. It is probable that even with a margin of less than one the fuzes would not arm, since at the acceleration required to swing the bell cranks outward the relatively heavy shutter is held in the *safe* position by frictional forces.

Prematuring is avoided when the round enters the water both by the time required to operate the bell cranks and by the partial interlocking action between the cranks and the firing sleeve as the latter moves forward upon water impact, which increases the arming pressure nearly 4 lb/in.² at a deceleration of 50 g. As the round reaches a region of less deceleration a short distance under water, the firing-sleeve releasing springs overcome both inertial forces and friction, restoring the firing sleeve to its original position and permitting the bell cranks to open. The shutter is then driven by the two springs into the *armed* position and locked by the two detents.

Prematures of this fuze at higher than normal entry velocity are with few

exceptions of the "dud" type, but a very small percentage of "live" ones have been encountered. The latter have been traced to fuzes in which the accumulated dimensional tolerances permit release of the shutter before release of the firing sleeve. It appears that a delayed release of the shutter by the bell cranks with respect to the firing sleeve is more effective in preventing "live" prematures than relying on the shutter mass, deceleration, and friction forces.

7.035. FIRING.—After the fuze is armed, the firing sleeve is maintained in position by the two firing-sleeve releasing springs. These springs also provide a restoring force, increasing with deflection, to return the sleeve to its initial position and prevent the fuze from firing either upon a series of successive small shocks or on any impact less than the minimum required for actual firing. A sufficiently heavy nose impact drives the striker ring and firing sleeve forward against the release-spring force, releasing the locking balls which are then forced outward by a component of the firing-spring compression, releasing the firing pin. A glancing impact of the round drives the striker ring to one side, camming the firing sleeve forward and releasing the locking balls as before. Disregarding friction, the ratio of side to nose sensitivity would be about 1:3, but the fuzes as produced actually measured between 1:4 and 1:6, which is not sufficient to obtain consistent firing on steel plates inclined 75° to horizontal. The forward sensitivity was adjusted by selecting the release spring force to give 100 per cent firing in the center of the wooden-deck target.

7.036. DEVELOPMENT OF FUZE.—On 3 July, 1942, the Rocket Group at CIT was requested by the Navy to design a fuze to serve the function of the Mk 135 but to be interchangeable with the Mk 131. If possible, it was also to be adaptable to Hedgehog ammunition, replacing the Mk 136, and to rounds used in the bombing of submerged submarines from low-flying airplanes or blimps.

In September, 1942, a preliminary model was completed, and tests were made with hand-made samples. This design was in general similar to the present fuze, except that (1) the diaphragm was larger, being 2.37 in. in diameter, (2) the bell cranks were not interlocked by the diaphragm button, necessitating an additional safety wire through the shutter, (3) the safety ring was omitted, and (4) the firing-sleeve restoring force (determining fuze sensitivity) was derived from a component of the firing-spring force by slightly tapering the ball-retaining hole through the sleeve. The few tests possible with the available samples appeared encouraging enough to continue the development.

The diaphragm button interlocking the bell cranks was added for safety reasons, eliminating the safety wire passing through the shutter. The safety ring and upper bell-crank hooks were incorporated for greater security against premature arming in Hedgehog rounds. Tests of smaller diaphragms showed that without affecting fuze arming the diameter could be reduced to about 2.12 in., permitting a corresponding reduction in body diameter. The diaphragm seat and associated gasket were added to simplify the manufacture of a one-piece body. At about this stage it was requested that the fuze be free from prematuring at velocities somewhat in excess of the usual 190 ft/sec maximum entry velocity, which, following the Mk 135 modifications, made it appear desirable to increase the arming pressure from the original 6 to 9-lb/in.² values to a 12 to 15-lb/in.² range. Since the arming pressure

was raised by increasing the firing-spring tension, it was found that the taper on the inside of the firing sleeve had to be reduced from the original 5° to a much smaller value in order to maintain fuze sensitivity within firing limits on the batten deck. The taper reduction so increased the ratio of frictional to firing-sleeve restoring force that production uniformity of firing sensitivity would clearly become a major problem. This difficulty was overcome by adopting one of the experimental designs of the Mk 142 fuze, which involved a straight bore within the firing sleeve as well as the addition of the two firing-sleeve releasing springs and guide pins. As a means of increasing further the entry velocity at which prematuring commenced, the partial interlock between arming and firing mechanism was incorporated, requiring a groove in the firing sleeve and another hook on each bell crank to engage the groove during heavy deceleration.

Initial recommendations for production called for a firing sensitivity range of 1.25 to 2.5 in. on the steel-block drop test, and an arming pressure range of 12 to 15 lb/in.² As the fuzes could not be held within the 3-lb arming pressure range during pilot production, a few additional tests were made to determine to what degree the specifications could be broadened, and results indicated that the arming range might be extended to from 12 to 18 lb/in.² for dynamic arming at 175 ft/sec entry. These limits were incorporated into final specifications for both local and eastern manufacture, and quantity production of the fuze was authorized by the Navy, with a provision, however, that since a tolerance study had shown that not all parts made in accordance with the drawings could be assembled into fuzes which would pass the functioning tests, only those fuzes which passed the sub-assembly, assembly, and over-all functioning tests would be accepted.

A number of proposals were made to reduce the tolerance accumulations which resulted in arming and firing difficulties. Closer tolerances were not at all feasible from a production standpoint. Since many of the difficulties encountered in manufacturing inspection of assemblies centered around interference between the lower bell-crank hooks and the firing sleeve, attempts were made to make the firing sleeve and striker ring in one piece and to remove the lower hooks altogether, accepting some reduction in prematuring entry velocity. The first alternative reduced the angle for 100 per cent firing from 65° to 45° , as determined by the slant plate test, so it was discarded. The second proposal reduced the entry velocity at which prematures commenced from 300 to about 250 ft/sec, which was considered too large a loss. Pilot manufacture of the fuzes was then continued on the original basis of partial selective assembly.

Among the first several hundred fuzes shipped from pilot production, some were found to be armed even with the safety wire in place. This serious fault was traced again to tolerance accumulations between the diaphragm seat and diaphragm, and was corrected by (1) further selective assembly, (2) closer diaphragm tolerances, and (3) the present screw adjustment between the diaphragm button and nut, which is made individually on each fuze and then locked by crimping. The button and nut had previously been made in one piece.

After quantity production was well under way attention was called to the possibility that the fuzes might not pass the safety drop test which was being

initiated as a requirement for all fuzes. Tests showed that a fuze of the design then current, either with or without the safety wire, would usually arm and fire when dropped in a 65-lb round nose-down onto a steel plate from a height of only 6 ft, instead of meeting the requirement that the fuzes be safe after a 25-ft drop. Production was again halted until methods of overcoming the difficulty could be devised with the fewest possible alterations in the thousands of fuzes already completed. Since only 0.036 in. impact deformation of the nose cap resulted in arming many of the fuzes, a very much heavier nose cap without the center stud and extending across the full diameter of the fuze was tried, but without success. Although the impact deformation was fairly effectively resisted, the value of deceleration on impact was correspondingly increased, causing the fuze mechanism to move forward by distorting the relatively thin diaphragm seat. Forward motion of the mechanism being equivalent to a backward motion of the diaphragm nut, the fuzes continued to arm and fire when dropped in rounds from a height of only about 12 to 15 ft. It was also found that temperatures around 0°F so reduced the impact strength of the thick steel nose caps as well as the steel fuze bodies that severe shattering was encountered, rendering the fuzes unsafe. The solution accepted, which did not involve disassembly of the fuzes already manufactured, consisted in surmounting the entire fuze nose with a drawn-steel cup, having a large internal clearance to the nose-cap stud and drilled with certain holes to control the deformation pattern at impact. The outside diameter of the cup was limited to a size that would permit the modified fuzes to be used in fuze liners, already manufactured, which had three hooks spaced around a small diameter. Fuzes modified with the protective cups are safe when dropped in 65-lb rounds at low temperature from 40 ft onto 1-in. plate backed by concrete, the deforming action of the cups absorbing the impacts so that the fuze nose-cap studs are not touched, and reducing the deceleration to a value which the diaphragm seats can withstand without distortion. The effect of the cups on underwater performance was determined to be negligible at 175 ft/sec entry velocity, increasing the arming depth about 10 per cent, although at 130 ft/sec, for which velocity the dynamic pressure wave has a much smaller amplitude, a larger percentage of the fuzes descended to the static arming depth before arming took place. The performance on wooden deck and slant steel plate was not affected.

Several changes were made in the fuze as production proceeded. Since arming pressure could not be maintained between the 12- to 18-lb/in.² limits, a request was received to widen the range to between 10 and 20 lb/in.² To avoid an increase in prematures, a compromise was reached in a 12- to 20-lb/in.² range, although experimental evidence being accumulated indicated the desirability for much narrower limits. In order to facilitate production, the use of die castings was proposed by the manufacturers for the relatively intricate head and base, as well as for the shutter, body, and nose cap. The greatly reduced impact strength of die castings at low temperatures eliminated consideration of the body and nose cap, but the cushioning action of the protective cup permitted the use of the alloy for the head, base, and shutter, and many fuzes were manufactured in this way. However, the slow dimensional changes which are also characteristic of die-

casting alloys eventually became apparent in the numerous failures of the press fit between head and base among fuzes within six months to a year following manufacture. The relatively low strength of the alloy also allowed deformation of the four base segments surrounding the shutter, even when the magazine was tightened by hand. This forced the striker ring and firing sleeve forward until the latter partially engaged the lower bell-crank hooks, interfering with and frequently altogether preventing fuze arming. The magazines of die-cast fuzes therefore had to be screwed down only snug and then staked in place—a procedure which lowered the fuze firing sensitivity.

Acceptance tests of production fuzes gave generally unsatisfactory results, due to arming failures. An average of 15 per cent (although running as high as 30 per cent in some lots) of the fuzes would not arm at depths up to 35 ft when fired at an entry velocity of 220 ft/sec, specified as a prematuring test. A higher percentage of failures would have been encountered had the fuzes been tested at the normal 175- and 140-ft/sec entries, where the dynamic pressure is lower, as in the ASR and Hedgehog. On the deck and slant plate firing tests where the rounds were simply dropped from the water surface to the targets submerged 50 ft, about 10 per cent arming failures occurred, and a few failures were found at target depths of 60 and 70 ft. It is presumed that most fuzes failing to arm in the prematuring test would have armed at a depth corresponding approximately to the static arming pressure. While these acceptance test results were not inferior to those of the first Mk 131 and 136 fuzes, the results were poor as compared with later mods of the fuzes then in use. It was also becoming apparent that improvement in the Mk 140 could be made only after extensive fuze modifications, which may not have been justified in view of the limited field of application. Production of the fuzes was therefore terminated, to be superseded by a revised design, Mk 156 and 158, of the underwater vane-arming fuzes.

7.037. REMARKS. THE MODIFIED Mk 140 FUZE.—A detailed investigation of the numerous arming difficulties of the Mk 140 fuzes disclosed the diaphragm to be the main source of trouble. Aside from space considerations, the original reason for having the diaphragm act against the firing spring, instead of being unloaded as in the Mk 135, was that the arming pressure would be controlled by the accurate and reproducible firing spring rather than by the diaphragm itself. Experience in the production of the large Mk 135 diaphragms had shown that a large change in arming pressure was caused by the normal variations in thickness of the sheet from which the diaphragm blanks were punched, two different diaphragm-forming dies being required by the small change in thickness across the width of a standard 6-in. rolled sheet in order to maintain arming pressure between the limits of 17 to 22 lb/in.² The arming pressure of Mk 140 fuzes without the firing spring bearing against the diaphragm was between 2 and 4 lb/in.²—a small value compared with the thrust of the spring (13 lb $\pm$ 0.25 lb) distributed over the effective area of the diaphragm. With arming pressure varying between 12 and 20 lb/in.² among uniformly manufactured fuzes, it was clear that the arming mechanism was not performing as intended in the original design. Observations made through transparent windows in special nose caps showed that while the air pressure used for

arming was being applied the loaded diaphragms underwent a series of twisting and buckling deformations, rarely repeating the same pattern, before finally snapping into the *armed* position. The reason for apparently normal fuzes exhibiting sudden failures to arm even at 30 lb/in.² pressure, followed again by normal values after release of the high pressure, was also discovered to be a chance diaphragm buckling in the bell-crank plane, which twisted the diaphragm button, thrusting the bell cranks in opposite directions, and locked the mechanism. It is probable that the maximum ratio of centrally applied load to diaphragm stiffness had been exceeded in the design, requiring as a physically unrealizable alternative that the load be distributed over the active diaphragm area for improved operation. A number of other factors which could change the arming pressure by at least 5 lb/in.² were also found in the course of the investigation, including simply loosening and then tightening the nose cap, type of sealing compound used on the diaphragm clamping surfaces to prevent air and water leaks, value of torque employed in tightening the nose cap, diaphragm cycling, and length of time in storage in the *unarmed* position.

It was evident that the fuze required a new type of diaphragm, meeting the following mechanical specifications:

1. A maximum deflection of 0.090 in.
2. A diameter not to exceed 1.900 in., in order to fit within the current nose-cap inside diameter.
3. An approximately linear pressure-deflection characteristic, as contrasted with the unstable snapping action of the diaphragm.
4. Strength sufficient to withstand rupturing under pressure of about 300 lb/in.², since the diaphragm must act as a water seal at depths of 600 ft.
5. A low hysteresis; appreciable values of permanent set following deflection will cause arming pressure drifts.
6. (a) A spring rate low compared with that of the firing spring, in order to make the fuze arming pressure independent of the ordinarily variable diaphragm and controlled by the accurate, ± 0.25 -lb tolerance firing spring; or, (b) an accurate spring rate comparable with that of the firing spring. In the event a diaphragm could not be designed to meet Requirements 3 and 6 (a), then it would become necessary to seal off the firing spring and depend solely on the diaphragm stiffness and effective area to control the arming pressure. This would require exceptional uniformity among diaphragms as well as unusually small values of hysteresis.
7. Ability to withstand pressures up to about 25 lb/in.² without exceeding the elastic limit. This safety factor is desirable in order to insure that the arming pressure will remain unchanged after routine production tests in which the applied pressure may exceed the normal arming pressure.
8. The arming pressure must be independent both of the type of sealing compound used to prevent leaks and of the torque employed in tightening the nose caps.
9. A reasonable corrosion resistance is necessary, especially if association with other metals remote in the electromotive force series makes cell action possible.
10. Reproducibility of characteristics over a testing cycle of at least ten arming measurements.

The use of either a corrugated flat diaphragm or a metal bellows was indicated as an answer, but difficulty of procurement appeared to be a serious obstacle. The corrugated diaphragm was the more desirable, since fewer fuze changes would have been necessary. A wide variety of designs were tried using common metals, but arming pressures were invariably too high and drifted seriously because of excessive hysteresis with even a 9-lb firing-spring load. Heat-treated beryllium-copper between 0.002 and 0.003 in. thick with deep corrugations appeared satisfactory, but occasional pinholes in the stock and the probability of leaks caused by only the slightest corrosion made it appear impractical. If the firing spring could have been sealed off, eliminating the load on the diaphragm, 0.004-in. heat-treated beryllium-copper moderately corrugated would have given excellent results, as the arming pressure was very uniform at 11 lb/in.² and diaphragm hysteresis was practically nonexistent. For two reasons, however, this diaphragm was abandoned: first, sealing off the firing spring shortened it to the point where excessive working stresses would have been encountered in even a 9-lb spring with certain tolerance accumulations, and second, the arming action would have been modified in an undesired manner. In both the Mk 135 and Mk 140 designs the fuzes remained safe with virtually no motion of the bell cranks until the arming pressure was reached, whereas the unloaded diaphragm, deflecting in proportion to the applied pressure, would begin to open the bell cranks as soon as pressure was applied.

Tests with the metal bellows immediately showed promise. Closed-end bellows, 1.87 in. OD, with two active corrugations required in compression with externally applied pressure an average of 1.5 lb/in.² for 0.075-in. deflection, with maximum deviations of 20 per cent above and below the average—a relatively small variation compared with the fuze arming pressure. The wall thickness of the bellows was 0.00575 in., the effective area 1.75 in.², and the over-all height approximately 0.650 in.; the bursting pressure was about 1700 lb/in.², and the maximum rated operating pressure 30 lb/in.²; the average hysteresis when the bellows was deflected to 0.090 in. under load was very low, amounting to 0.0005 in.

Experimental verification of the conclusion that the original diaphragm was responsible for most of the erratic arming pressure variations of the Mk 140, as measured in the laboratory, was obtained when a group of 117 fuzes picked at random from new production were used for test. The fuzes originally showed arming pressure ranging from 11 to 28 lb/in.² With no alteration of the fuzes except the substitution of a deeper nose cap to contain the bellows, the arming pressures of the entire group measured between 9 and 10.75 lb/in.² Stability tests were also satisfactory; disassembly of the fuzes followed by reassembly did not change the arming pressure more than 0.5 lb/in.², arming pressures were completely independent both of torque employed in tightening the nose caps and of the type of sealing compound used, and the effects of cycling (repeated arming and disarming of the fuzes) were limited to a total of 0.5 lb/in.² downward drift in arming pressure. While a range of only 1.75 lb/in.² in arming pressure was encountered in the measurements, analysis of fuze and bellows tolerances showed that a range of 2.2 lb/in.² could be expected in manufacture.

The uniformity in arming pressure (at least when measured statically) now possible in the fuze made it desirable to undertake other operating improvements not involving mechanism parts which would be difficult to alter in reworking the fuzes. Two of the most valuable improvements were considered to be a reduction in maximum arming depth, when the round is fired into the water, to the 25 ft originally requested by the Navy, and an increase in the prematuring entry velocity. Also, since the partial interlock between arming and firing mechanisms was responsible for great difficulties in manufacture and had increased the prematuring velocity by only 50 ft/sec, the elimination of this device was important. On the assumption that there is no change in the shape, weight, entry velocity, or entry angle of the projectile, and that the fuze port is located in the nose of the round, it is evident that in the absence of partial interlock the arming depth will be determined by the port hole diameter, the cavity volume over the diaphragm or bellows, and the fuze arming pressure.¹ It may be noted that the use of any form of valve to control water flow into the cavity is eliminated by conditions of dirt and corrosion encountered in service use.

A group of fuzes with the new bellows were provided with nose caps having a cavity volume, with the bellows in place, of 21.5 cm³ instead of the 11.5 cm³ of the standard Mk 140. The new volume was based on calculations of the relation between pressure within the cavity and fuze depth for several entry velocities. Orifice coefficients were established over a wide range of pressure by static measurements. A few points along the curves were located by measuring the amounts of water trapped within actual fuze cavities by firing fuzes, whose ports were sealed by impact, against steel plates at various depths. Port hole size was retained at 0.055-in. diameter. All fuzes were modified further by removing the tips of the lower bell-crank hooks and squaring off the cranks at this point, leaving a flat surface adjacent to the firing sleeve so that, aside from friction, the partial interlock was eliminated. In 58 tests of the new fuzes in 7.2-in. 68-lb flat-nosed rounds at an entry velocity of 410 ft/sec and angle of 45° no prematures occurred. Thirty-nine of the fuzes had a protective cup, while in the remaining 19 the cup was removed to make the test more severe. Similarly, at entry velocity of 320 ft/sec there were no prematures in 23 tests, 21 having been made without protective cup. As a further indication of the arming stability of fuzes with metal bellows, the arming pressure of 23 fuzes measured after the 410-ft/sec tests showed changes ranging from only 0 to 0.5 lb/in.², although the bellows were slightly deformed by the high water pressures.

¹ Considered in terms of its electrical analogue, fuze arming is equivalent to the action of a biased thyatron, driven through a half-section low-pass filter by a half-cycle single-impulse generator whose wave shape duplicates the entry water pressure wave at the fuze ports. The series inductance, of low power factor, represents the restriction to water flow by the ports, the capacity is approximately equivalent to the cavity volume, while the biased gas-filled trigger tube duplicates the value of pressure required to arm the fuze. The transmission time delay of both the hydraulic filter and its analogue will of course depend on the selected values of the three elements, but if an arming pressure corresponding to a depth of 25 ft is adopted and the port hole diameter is determined by a minimum desirable safety-wire size, then the cavity volume remains the only element to be varied.

Approximate arming depth determinations of the modified fuzes were made at different entry velocities. When the 7.2-in. flat-nosed rounds were wire-snipped from just above the water surface, the fuzes armed at about 33 ft. When fired into the water at velocity between 130 and 220 ft/sec, fuzes arming at more than 9.75 lb/in.² armed at depths corresponding very closely to their static pressure, while fuzes arming at less than 9.75 lb/in.² armed at between 15 and 20 ft for entry velocities above 150 ft/sec. At 310 ft/sec, and undoubtedly at lower velocities, all fuzes were being armed by the dynamic pressure wave transmitted to the interior of the fuze, at a depth of about 15 ft. Removal of the protective cup reduced the arming depth not more than 10 per cent.

The margin against prematuring at 410 ft/sec was determined in two ways—first, by lowering the arming pressure, and second, by reducing the cavity volume of the fuzes until prematuring began. The lowered arming pressure for the first test was obtained by reducing the firing-spring force with special springs. At arming pressures greater than 8.12 lb/in.² no prematures occurred. At arming pressure of 8.12 lb/in.² one fuze in five prematured; at 8.0 lb/in.² three in eleven prematured; at 7.75 lb/in.² two in four; while at pressures lower than 7.75 lb/in.² nearly all fuzes prematured. For the tests with reduced cavity volume, spacer disks of various thicknesses were attached inside the nose cap to the top of the cavity chamber. Among fuzes arming at 10.0 lb/in.² prematures were encountered in all fuzes having cavity volumes ranging from 13.5 to 18.0 cm³. Among fuzes arming at 9.5 lb/in.² or less, virtually all having a cavity smaller than 19.0 cm³ prematured. At an entry velocity of 310 ft/sec no prematures occurred even with arming pressure of 9.0 lb/in.² and cavity of only 13.5 cm³—the smallest volume possible without interfering with bellows action.

The margin of safety against prematuring at 410 ft/sec in the 7.2-in., flat-nosed, 68-lb rounds in the above tests was not large. If the entry velocity is below the critical value that divides static from dynamic arming, raising the arming pressure would increase the arming depth to a value greater than the desired maximum of 25 ft. Increasing the time constant of the filter system appeared the only way to provide a larger margin, up to the point where, because of the delay, the arming depth would begin to increase over the 25-ft limit, at the lowest projected entry velocity of 130 ft/sec. However, since the clearance between the nose cap and the inside of the protective cup was already at the minimum to pass the safety drop test, and since a reduction in port hole size was undesirable on account of the difficulty of drilling the small holes within tolerances, the only remaining alternative was to add another element to the filter system. This was done by providing a second orifice in the nose-cap cavity space, consisting of a flat disk 0.040 in. thick with a 0.262-in. diameter hole in the center; through the hole passed the bellows stem, now held accurately at 0.250 in. diameter. The clearance between the hole and stem amounted to an orifice equal in area to that of the two 0.055-in. diameter port holes, and was thought to be about as small as practicable on account of the corrosion existing under service conditions. The volume to be occupied by the incoming water for fuze arming was divided in two by the orifice plate, so that at least half the water entering the fuze before arming took place would be forced to

pass through the orifice.¹ Eight fuzes made in this way and having low arming pressure ranging from 7.25 to 7.75 lb/in.² gave no prematures at 410 ft/sec entry velocity when mounted in 7.2-in., flat-nosed, 68-lb rounds, but prematures were encountered among other fuzes having arming pressure less than 7.25 lb/in.² This result was an improvement over the single cavity fuzes at high entry velocity, and tests at 175 ft/sec showed only a very slight increase in arming depth. However, in tests made with a 100-lb round-nosed bomb (which gives a long-sustained deceleration under water), and intended to duplicate approximately the entry conditions for some aircraft applications of the Mk 140, there was little difference, as anticipated, between the single and dual cavity fuzes, both types yielding about 50 per cent prematures with 7.0-lb arming pressure fuzes at an entry velocity of 325 ft/sec. Increasing the arming pressure of single cavity fuzes to a range of 8.0 to 8.5 lb/in.² eliminated prematures in the 100-lb bombs at entry velocity up to 350 ft/sec, but no tests were made at a higher velocity. As the over-all improvement did not appear to justify the increased manufacturing complexity, further development of the dual cavity filter was dropped for this fuze; however, the principle later was applied successfully to gas-pressure-arming base fuzes.

A further attempt was made to increase the prematuring margin at 410 ft/sec entry velocity by utilizing the inertia of a mass pressing against the inside of the bellows during deceleration. As mentioned previously, the 1.87-in. OD bellows was mounted with the open end toward the fuze interior. This permitted a 26-gm disk and thin rubber washer to be placed inside the bellows without interfering with the arming motion. The disk and washer both were drilled to allow the bellows button to pass through with a loose sliding fit. The under side of the disk was recessed to rest on the top of the fuze head and not on the bell cranks. This arrangement allowed the disk to press against the inside of the bellows during underwater deceleration, while preventing the disk from adding its inertia to the diaphragm system during forward acceleration, as in Hedgehog firing. The purpose of the washer was to act as a cushion for the disk if the fuzes were to be transported nose-down. At a deceleration of 40 g and an effective bellows area of 1.75 in.², the calculated increase in fuze arming pressure amounted to 1.3 lb/in.² In tests at 410 ft/sec made with 68-lb flat-nosed rounds, the presence of the disk appeared to have no influence on prematures.

A lengthy series of tests to determine fuze arming depths at low entry velocity yielded results which showed that enough fuzes were failing to arm at the calculated depths to indicate clearly the presence of some other interference with fuze arming, previously obscured by the erratic diaphragm action. The difficulty was traced to leakage of water past the gasket into the fuze liner, which compressed the air

¹ In the electrical analogue this was approximately equivalent to adding another filter half section by splitting the condenser into two equal parts and interposing another inductance equal to the first coil. The loss in time constant due to halving the condenser from its previous value would be considerably more than compensated by the new inductance, and the sharp peak value of the generator wave due to water impact of flat-nosed rounds would be attenuated to a marked degree in passing through the network. While other configurations of low-pass filters exist, the type adopted appeared to be the one most easily realizable within the physical limitations of the fuze.

therein and forced it past the magazine threads into the fuze interior, raising the fuze arming pressure. In ordinary fuze tests the liners had been left empty below the fuzes, so that considerable amounts of water had to leak past the gaskets before the air pressure increases became appreciable, and the time usually required to raise the fuze internal pressure significantly was long in comparison with the fuze arming time. However, when dummy spacers were placed in the liners to occupy the volume taken up by the two auxiliary booster charges specified for actual service use, the effect of leaks on fuze arming became very apparent, and the gaskets were shown to be of little value.

A wide variety of means for sealing the magazine threads were tried, but not found reliable even at pressures of only 90 lb/in.² Cements and luting compounds were rarely effective in the coarse, loose-fitting threads at pressures exceeding 15 lb/in.² A taper thread on the magazine alone would have been moderately effective with luting, but the wide tolerances in the body and over-all mechanism length meant that in many instances the thread would tighten before the magazine was seated against the lead-in disk, leaving a gap in the explosive train. If the taper thread were forced, the relatively weak fuze base segments might often be bent inward, jamming the arming mechanism. The inside diameter and concentricities of the standard fuze liners and the wall thickness of the fuze body did not permit a sealing cap of any type to be screwed over the entire fuze end after the magazine was in place. In addition to leaks past the magazine threads, air was found also to leak readily past nearly all the guide pins. In some of the production fuzes received, water could be forced at low pressure past the thin diaphragm seat gaskets, which had wrinkled as the nose caps were tightened. That it is imperative for fuze sealing to be positive even under production conditions is evident when it is realized that the arming pressure cannot be measured after explosive elements are loaded and the magazine is screwed in place.

7.038. PROPOSED MODIFICATION OF MK 140 FUZE.—Further extensive changes in the fuze obviously were necessary. Since an entirely new fuze body was essential, the opportunity arose to redesign parts of the fuze, excepting the internal mechanism and incorporating other improvements so that the fuze would meet more closely the requirements of recently proposed applications. The redesign was intended to accomplish, if possible, the following:

1. Elimination of the protective cup. First, the cup had been found to cause a slight increase in the underwater dispersion of rounds dropped nose-down at low entry velocity. At higher velocity and more usual entry angles the lift of the cup probably would increase dispersion somewhat further, but no data on this point are available. Second, the cup added 30 per cent to the fuze weight. Third, the cup extended 2.6 in. beyond the face of the round, decreasing the effective fuze sensitivity on the wooden decking of a submarine. Since the diameter of the projecting cup (2.8 in.) was less than the batten width (3 in.) plus the two adjoining spaces each 0.75 in. wide, impact on a single batten was a frequent occurrence. Inasmuch as impact of a 60-lb round on one batten invariably broke it, the round was not brought to rest until the 7.2-in. diameter face contacted adjacent battens. For fuze sensitivity of 40 g and a projectile underwater terminal velocity of 23 ft/sec, the maximum distance in which the projectile can be brought to rest and

fire the fuze becomes only 2.4 in.; this is based on the assumption of uniform deceleration over the stopping distance, which is known to apply roughly for batten impact so far as fuze inertia-firing mechanisms are concerned. With the cup projection of 2.6 in. and frequent fuze sensitivities of the order of 50 g, it was certain that some fuzes would fail when contacting a single batten of a deck, especially when near a span center. Fourth, the cup size and shape interfered seriously with nose fairing of fast-sinking contact charges.

2. Fuze projection beyond the projectile nose must be kept to a minimum, not to exceed 1.2 in. For small projections of the order of 0.6 in. the rounds effectively contact a minimum of two deck battens at once, at least doubling the impact deceleration force available to fire the fuze. It should be noted that this is equivalent to doubling the fuze sensitivity without lowering the prematuring entry velocity. The maximum figure of 1.2 in. is derived from the fact that during a portion of the underwater trajectory after fuze arming, an ASR projectile will usually drop to a minimum velocity of only 16 to 18 ft/sec until the entry bubble is stripped off at a depth of about 40 ft, when it begins to accelerate toward its terminal velocity, reached at about 60 ft. For a velocity of 16 ft/sec the maximum deceleration distance for firing a 40-g fuze becomes 1.2 in.

3. Elimination of joints, such as a nose cap separate from the body, left exposed after the fuze is screwed into the round. Since at an entry velocity of 400 ft/sec a 7.2-in. 68-lb, flat-nosed round encounters a peak water pressure approximating 2000 lb/in.², it is impossible to be certain that threaded or press-fit joints exposed to this pressure will not leak. For safety reasons also it is desirable that no threaded joints be exposed, since it is known that at least one serious accident was caused by the separation of two parts of a fuze during an attempt to remove a badly corroded fuze from a live round.

4. Mounting threads should be integral with that part of the fuze which projects from the round after the fuze is screwed in place. This too is desirable for safety reasons, so that even the mistaken application of a pipe wrench in removing a tight fuze from a round would not result in unscrewing a joint, for example, under the nose-cap head.

5. The maximum fuze length measured from below the external mounting shoulder must not exceed 4.515 in., and the maximum fuze diameter should not exceed a nominal 2.25 in. The length dimension, equal to that of the Mk 131 and 136 fuzes, would permit the new fuzes to be installed in the standardized liner designed primarily for the former fuzes and produced in very large quantities. A maximum diameter of 2.25 in. is desirable in order to fair the fuze nose more readily into the nose contours of fast-sinking contact charges, and because of the chucking capacity of the most common automatic screw machines.

6. Fuzes must be able to withstand a safety drop test with ample margin in a 104-lb bomb dropped from 40 ft over a temperature range of -20° to $+150^{\circ}$ F. This requirement is necessary if the Mk 52 or similar bomb were to be carried by airplanes operating from carriers.

7. Bell cranks must release the firing sleeve before the shutter, regardless of fuze tolerances, to avoid any possibility of live prematures.

8. Alignment between port holes and bellows stem groove must be accurate

enough to permit easy removal of the safety wire. The scatter bomb cluster was designed to withdraw fuze safety wires at the time the cluster was separated radially by a small explosive charge. Wires as tight as those of many of the production Mk 140 fuzes would disturb the air flight of the round.

9. Fuzes must remain watertight at static pressures of at least 300 lb/in. Since fuzes are to be operative at depths of at least 600 ft, and it has been found that the sidewise firing sensitivity is greatly reduced by the presence of water inside the fuze, the bellows must have a high rupturing pressure along with the other seals.

10. The fuze must be sealed tightly against all air and water leaks. The external gasket cannot be relied on to serve this purpose, first, because the exceptionally wide tolerances of the fuze liner make positive sealing impossible, and second, reliance on an external gasket transfers the responsibility for an important part of fuze performance to service personnel.

11. The static arming pressure and cavity time constant must allow fuzes to arm at a maximum depth of 25 ft, except possibly when shipboard rounds are dropped over the side or thrown very short distances. An arming depth of much less than 25 ft would be desirable, of course, under ordinary conditions. While shallow arming could be provided, it is involved also in fuze safety as noted in Item 13 below.

12. Both the maximum arming depth and minimum prematuring entry velocities are not to be changed over a fuze temperature range of -20° to $+150^{\circ}\text{F}$.

13. Without safety wires, the fuzes must neither partially arm nor become unsafe, either because of temperature changes within the above range, or because of superimposed atmospheric pressure changes encountered under different weather conditions or during aircraft flight.

14. Prematuring entry velocity must be safely above 320 ft/sec in the Mk 52 104-lb round-nosed bomb at entry angles from 65° to 90° , and amply above 400 ft/sec in the 41-lb, 6-in. diameter flat-nosed scatter bomb.

In addition to these requirements, three other simple modifications were necessary in the fuze mechanism itself. First, it had been found among some fuzes that the firing-sleeve pins were touching the diaphragm seats before the firing sleeves had moved forward quite far enough to release the locking balls and firing pins. The difficulty was caused by large tolerance accumulations overlooked in the production drawings, and probably was responsible for some of the fuze firing failures that occurred in the acceptance tests. While no pins were found long enough actually to prevent firing in the original fuzes on the maximum steel-block drop height specified, the fuzes were firing only by slightly distorting the diaphragm seat, and the drop sensitivity was often increased as much as 0.5 in. when the pins were shortened. The difficulty was first discovered in experimental solid-nose-cap fuzes when it was found that some mechanisms would not fire at all when the fuze head was supported by a block of metal extending inward to a diameter less than the pin-guiding holes. The fuzes are readily tested for this defect by passing a rod, equal in diameter to the maximum tolerance of the firing pins, through the firing-pin hole with the locking balls in place and observing whether the pins are even with or extend above the fuze head. Second, the compressed length of some of the production 13-lb firing springs was found to be too short in a few fuzes, in the *armed*

position. Spring calibration tests showed that the tension in such springs increased very rapidly as the fuze armed, since only the center coils remained separated and still active. This defect was eliminated in the design of the firing springs used in the new fuzes. Third, the inner end of the diaphragm button would sometimes catch on the bottom of the bell-crank grooves in the head where they intersect the firing-spring hole, interfering with fuze arming. For the new fuzes the inner ends of the grooves were filed down to clear the button at its maximum possible depth.

Part of the above requirements are met by the proposed fuze shown in the accompanying drawings (Figs. 109 and 110), but the development is not complete. The protective cup has been eliminated and the fuze projects a maximum distance of only 0.62 in., including the gasket thickness, from the projectile nose. The weight has been reduced from 3.5 lb to 2.8 lb, the same as for the Mk 156 and 158 fuzes. There are no joints exposed after the fuze is screwed into the round, and any tool used for removal will not separate parts of the fuze, as the mounting threads are integral with the solid projection of the fuze beyond the nose of the round. For further fuze safety the threads between the body and nose are left-hand, so that the fuze cannot be separated even if the body should rust tightly within a fuze liner. The fuze dimensions meet the requirements of 4.515 in. maximum length below the nose shoulder, and the nose is made from $2\frac{1}{4}$ -in. bar stock.

The safety drop-test requirement was difficult to meet. Carbon steels used for the fuze nose did not show sufficient strength at normal temperatures, and low-temperature embrittlement at 0° and -10°F was severe enough to cause many fuze noses to shatter on impact, arming and firing fuzes in nose-down drops of only 25 ft in 65-lb steel blocks. The most effective means of avoiding loss of impact strength at low temperatures is through the use of nickel-bearing alloys. Monel alloys and certain varieties of stainless steel are satisfactory, but the strong electrolytic cell action taking place in the presence of salt water between stainless steel and brass limited the choice of Monel to prevent destruction of the relatively thin brass bellows in close proximity to the fuze nose. Very little cell action will take place between brass and the Monels; and the latter alloys have the unusual property of maintaining and sometimes increasing their impact strengths down to temperatures as low as -300°F . Safety drop tests were made with fuzes having both hot-rolled and cold-drawn Monel noses. These tests were made with the fuzes mounted, not in inert-weighted standard sheet-metal heads, but in steel blocks made to weight, which duplicated the nose contour of a standard round. This was done in order to make the test conditions more severe than any encountered in service use, in which deformation of the bomb case would absorb some of the impact shock. Thus, the fuzes themselves had to resist the entire shock. Further, all fuzes were provided with safety wires made from music-wire steel of a size only 0.0015 in. less than the port hole diameter. It may be noted that with the safety wires in place, fuzes will always arm more readily for a given backward distortion of the noses than if the wires are omitted. The drop tests showed that while the cold-drawn Monel noses were safe in steel blocks weighing 104 lb when dropped from 25 ft, a 40-ft drop resulted in a permanent inward distortion of 0.040 in., enough to arm some fuzes. However, heat-treated "K" Monel noses yielded excellent results, permanent inward deformations of only 0.002 in. and 0.003 in. being measured in two tests with

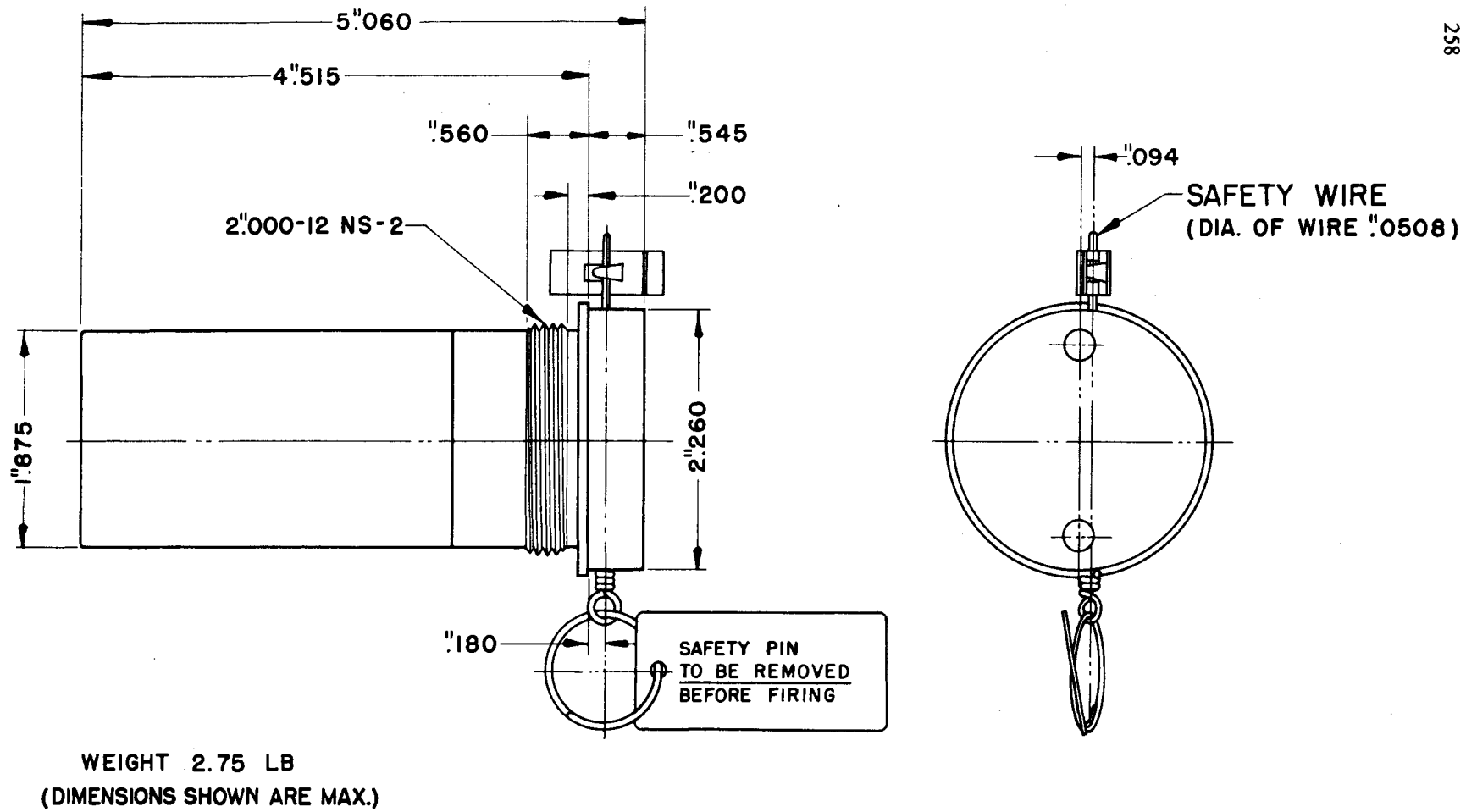


FIG. 109. Outline view, proposed modification of Nose Fuze Mk 140.

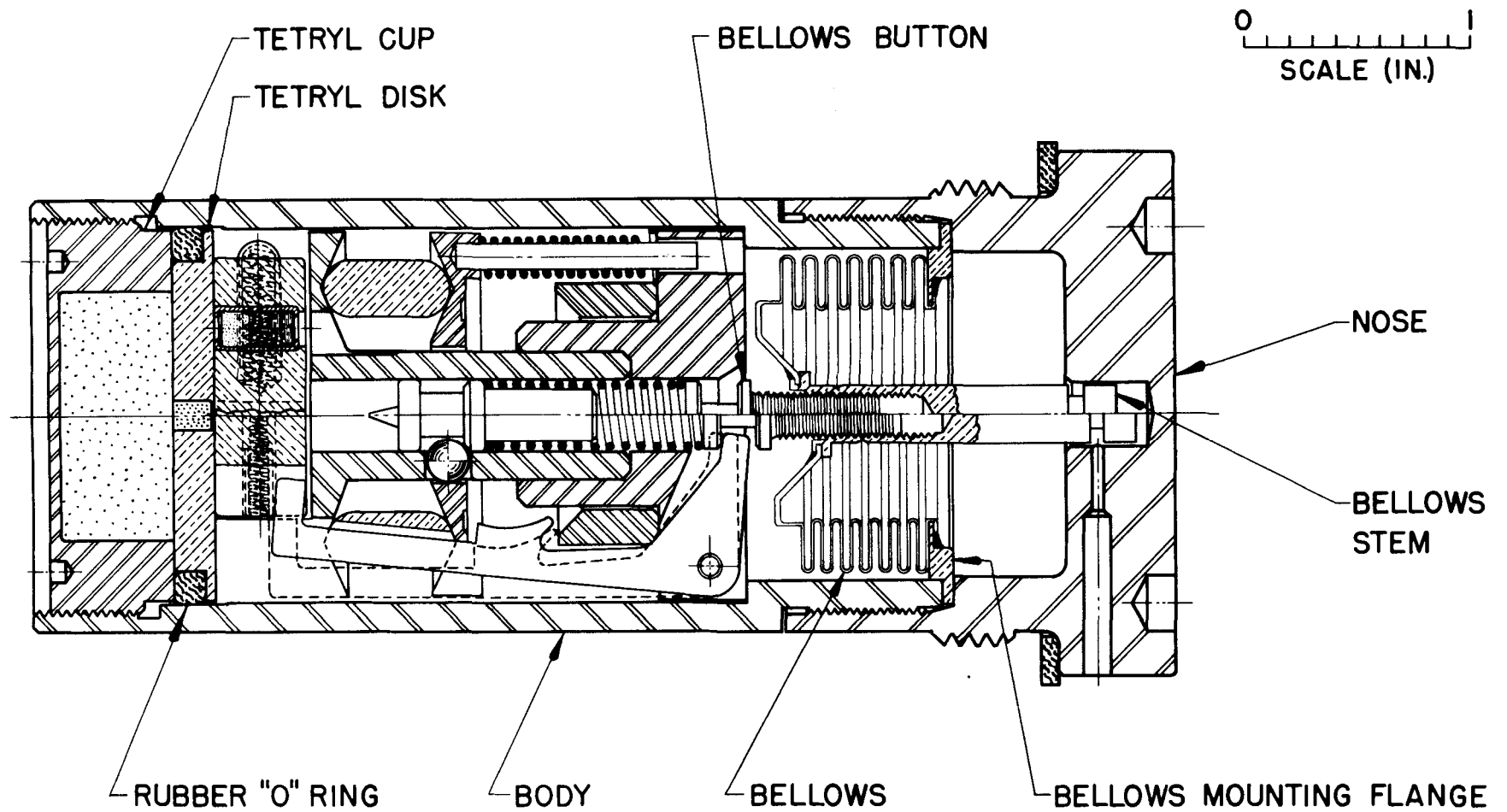


FIG. 110. Proposed modification of Nose Fuze Mk 140, unarmed. The upper half of the fuze is shown revolved 90° and with the bellows extended.

the 104-lb steel block dropped nose-down from 40 ft onto 3-in. steel plate backed with reinforced concrete. The two latter tests were made with standard external gaskets on the fuzes, and with adapters of SAE 1040 steel to duplicate the fuze mounting conditions provided by actual fuze liners. The adapters were screwed very tightly against a wide flat seat in the steel block, and carried the maximum internal thread chamfer specified by the liner drawings, so as to give the least support to the fuze noses. The two fuzes dropped neither armed nor fired, and both shutters were locked even more securely than normally in the *unarmed* position, as the bell cranks had been bent by the inertia of the firing sleeves and striker rings, forcing the lower ends of the cranks into the deepest possible engagement with the shutter slots. The machined heat-treated noses, before the drops, gave hardness readings of 348 and 373 Vickers, equivalent to 330 and 356 Brinell, or 36 and 39 Rockwell C—the difference arising from two dissimilar age-hardening time schedules. There are no dimensional changes in “K” Monel from heat treatment.

A simple die change is necessary to meet the seventh requirement, and could be incorporated at the same time that the lower bell-crank hooks were removed and the cranks squared.

Accurate alignment of the port holes with the bellows stem groove is readily accomplished by turning the groove after the bellows subassembly is completed. A special driving fixture is used, which temporarily locks together the bellows mounting flange and stem with the bellows at its free length, and locates the groove at a fixed distance ahead of the mounting flange regardless of variations in bellows free length. At fuze assembly a simple gauge is used as the bellows assembly is being screwed on the bellows button, assuring very close alignment with the port holes of any nose cap.

The requirement that the fuze remain watertight at pressures up to 300 lb/in.² is met by avoiding excessive tension on the joint where the bellows stem is spun and soldered over the hole punched in the closed end of the bellows. Tests have shown this joint to be the weakest in the bellows assembly, failing at 250 to 300 lb/in.² unless some means is provided to relieve a part of the tensile stress. By forming the 0.0225-in.-thick closed end of the bellows inwardly to make room for the spun and soldered joint as well as the upper flange of the bellows button, the fuze head supports the end of the bellows as it deforms under extreme pressure somewhat beyond the normal *armed* position, eliminating most of the tension on the stem joint. This design enabled the bellows to withstand a pressure of 600 to 650 lb/in.², measured with the maximum clearance between bellows and head encountered with the fuze and bellows tolerances specified. The rupturing pressure of the thin bellows wall itself was measured repeatedly at about 1000 lb/in.² No difficulties were encountered in the open end bellows seal, where it is spun and soldered to the mounting flange.

Requirement 10 is sufficiently important to merit a more detailed discussion. Complete sealing of the fuze, under constant temperature and pressure conditions and with means for temperature compensation, appears to be the most practical method in the existing fuze of preventing erratic disturbances in fuze arming pressure by air and water leaks, when the wide variety of service operating conditions is taken into account. In addition, sealing prevents the fuze from “breathing,”

which, especially in salt air, induces corrosion of the mechanism. The alternatives to sealing with temperature compensation are either sealing with partial exhaustion of the air, or venting. Evacuation of the fuze is not desirable from a loading plant production standpoint and it is doubtful that a vacuum could be long maintained in the presence of the compressed tetryl booster pellet. Also, the partially exhausted fuze would require a much stronger firing spring, and 13 lb is the maximum strength possible in the available space without overstressing the wire. However, partial exhaustion of all or part of the fuze may be considered as a possibility if a complete redesign of the fuze is ever contemplated, since the effects of temperature variation on arming pressure are made negligible; moreover, failure of the vacuum acts to make fuze arming more difficult and prematuring even less likely. Venting of the fuze does not seem desirable for many reasons, besides the tendency toward corrosion of the mechanism from "breathing." To prevent too rapid admission of air, the hole must be minute in size and therefore would be susceptible to closing by dirt and corrosion. Even a vent 0.004 in. in diameter would pass air at a rate of about 4.5 cm³/sec at a pressure of only 50 lb/in.² and temperature of 70°F. If the vent were made through the fuze body it would connect with the air in the fuze liner, which would change pressure if the liner happened to be sealed by the fuze gasket and the round were left in the launcher with the nose exposed to the sun. A vent made through the bellows stem and opening into the nose cavity would solve several problems, but, in addition to being especially subject to corrosion, it would make impossible an accurate determination of static arming pressure at the time of manufacture, and would interfere with a simple test for other leaks through the bellows assembly. Leakage of water through a 0.004-in. vent would be inappreciable, amounting to only about 0.34 cm³/sec at a pressure corresponding to a depth of 300 ft. While the vent must act slowly to avoid excessively rapid admission of air, it must act quickly enough to equalize barometric pressure in rounds dropped from moderate altitude, in order to avoid prematuring upon water entry due to the internal fuze pressure lagging behind the external air pressure changes. This difficulty is avoided entirely in the sealed, temperature-compensated fuze.

The current model of the proposed fuze has been sealed effectively only by employing both a rubber "O" ring around the tetryl disk, compressed into a definite volume by tightening the magazine against the disk, and by applying cement to the last few threads of the magazine at assembly. In addition the recessed end of the fuze is flooded with two separate applications of lacquer. The O ring by itself is not entirely effective against low pressure, but the lacquer and cement resist all pressures up to a point much higher than that at which the rubber ring begins to seal. Thus, the lacquer and cement easily exclude air at pressure differences created by temperature and altitude changes, while at projectile water entry the high pressure breaks the magazine thread seals but cannot force air past the O ring. If a test hole, to be closed later, is not left through the fuze body, care must be taken not to cement more than the last few threads of the magazine, for if all the threads are covered the internal fuze pressure will rise between 3 and 6 lb/in.² from air compression as the magazine is screwed into place. To aid further in keeping the fuze airtight, the tetryl disk is made similar to that of the Mk 156 and 158 fuzes, the pellet recess not being drilled completely through. The need for seal-

ing other than the O ring is not immediately apparent in testing the fuze, but temperature-change tests carried on for several weeks without cement or lacquer show that the internal fuze pressure will begin to equalize past the O ring in from 6 hours to 4 days, the entire equalization taking place in a short time after it starts.

Requirement 11 necessitated extensive changes in the fuze body and bellows arrangement from the first fuze with large diameter bellows. The cavity volume was restricted by the reduction in fuze diameter, by limitation of nose projection beyond the projectile face, and by the severe drop test which required that the fuze mechanism be supported against any forward movement by a shoulder of small diameter extending all the way to the nose impact surface. The space occupied by the bellows also had to be increased, as a small diameter bellows of desirable wall thickness required numerous convolutions to lower the spring rate to a range satisfactory for fuze operation. Extension of the fuze deeper within the liner, to the maximum of 4.515 in., shortening of the magazine, and inversion of the bellows so that its own volume could be utilized, enabled the desired cavity volume to be attained. However, the spring rate of a bellows in extension, that is, with operating pressure internally applied, is both higher and much more variable than when the same bellows is operated in compression with pressure externally applied, and in addition tends to be nonlinear. The measured increase in spring rate of the 1.37-in. OD bellows used in the new fuze, when operated in extension, amounted to an average of 49 per cent over the rate with the bellows operating in compression, and the variation in rate was 2.5 times as great. These difficulties were overcome, however, by operating the bellows, as the fuze armed, from an initially compressed condition to the free length of the bellows, instead of in extension from the free length. The compression was held to 0.090 in. in fuze assembly, as this value is equal to the maximum button travel required in arming to push the bell cranks outward against the body interior, and was well within the 0.290-in. limit for the bellows. The final cavity volume for the current design averaged 25.0 cm³ unarmed, increasing to 26.5 cm³ as the fuze armed. The 25-ft limit on static arming pressure was met by reducing the firing-spring force to 9 lb, and by the operation of the bellows from an initially compressed to a free length as the fuze arms. While the effective bellows area was reduced from 1.75 in.² in the original 1.87-in. size to 1.00 in.² in the 1.37-in. unit, the addition of more convolutions and a reduction in wall thickness to 0.00425 in. lowered the spring rate so that the effect of bellows variations on arming pressure is less than before. However, the reduced effective area diminished the thrust derived from unit pressure applied to the bellows, so that normal differences in the force necessary to arm a group of fuze mechanisms will be reflected as a wider spread in arming pressure. In spite of this factor, the static arming pressures among a group of 21 fuzes tested differed by only 1.3 lb/in.², although a maximum variation about twice as great would be anticipated with current fuze and bellows tolerances, which could be improved by slight changes in the firing pin. The arming pressures ranged from 9.8 to 11.1 lb/in.², measured with fuzes sealed at atmospheric pressure and with the magazine cavities filled. A reduction in specified firing-spring force to 8.5 or 8.0 lb may be necessary to bring the maximum arming pressure measured among a large group of fuzes

more precisely within the 25-ft depth limit. The added compression of the firing spring as the fuze arms will bring the minimum tension of such springs close to the 9-lb lower limit sometimes specified for detonators.

Another effect of sealing is to increase the arming pressure over that of a vented fuze, since the air within the fuze is compressed as the bellows extends to its *armed* length. Since the increase depends on the internal volume, and some air may leak outward past the O ring at the low pressures, all fuzes were provided with a dummy load to fill the magazine cavity. The increase in internal pressure due to arming measured 2.5 ± 0.1 cm of mercury, equivalent to 0.5 lb/in.^2 , which is reflected as an equal increase in fuze arming pressure over that of a vented fuze. This test is reproducible enough to indicate clearly when the bell cranks are resting incorrectly on the striker ring instead of on the firing sleeve, as sometimes happens if the ring is turned slightly out of position during fuze assembly.

Requirement 12 follows general specifications for the original Mk 140 by the Bureau of Ordnance. It is not met by the present uncompensated fuze, which if sealed at 65°F would decrease and increase 2.4 lb/in.^2 in arming pressure at the -20°F and $+150^\circ\text{F}$ extremes. It is known from the few field tests made on the fuze that the maximum arming depth would be increased to nearly 31 ft at the upper temperature limit, but it has not been ascertained whether prematuring at 400 ft/sec entry would be encountered at the lower temperature limit with the fuzes mounted in scatter bombs, or at 320 ft/sec in Mk 52 bombs. It was intended to provide temperature compensation in the fuze in a small space above the fuze head and below the bellows, but this development was not completed. The compensation was to be in the form of a narrow coiled bimetallic strip, which would turn the forward flange above the bell-crank groove in a new two-piece bellows button. Coarse threads inside the separate flange and on the button shank were to translate the angular movement into slightly greater or less distance of button travel before the bell cranks began to open, causing the bellows to operate against the correspondingly stronger or weaker firing spring at arming. Initial bellows compression would be increased to somewhat more than 0.090 in. So long as the seals maintained the fuze airtight this device was expected to be positive and accurate in action, since the bimetallic element would have to overcome only the slight screw-thread friction, the upper flange of the bellows button being free and not in contact with the bell cranks until after the fuze starts to arm. Radial roughening of the under surface of the flange was intended to prevent possible backward rotation of the flange on the coarse threads upon contact with the smooth upper edge of the bell cranks; however, this may not have been necessary, if the bimetallic element possessed sufficient angular activity per unit temperature change to reduce the thread pitch to a self-locking value. Since the weight of the element is negligible, there would be no appreciable increase in the effective mass of the bell-crank-and-bellows assembly that might induce prematuring on forward acceleration of the Hedgehog. Except for rapid temperature changes of large magnitude where the air confined within the fuze might not closely follow the temperature change of the bimetallic element, the compensation should be nearly exact.

The factor limiting the lowest operating temperature of the fuze is expected to

be the freezing of water as it enters the small port holes, rather than the reduction in arming pressure of uncompensated fuzes. From a few measurements made in early experiments on the first production models of the original Mk 140 without protective cup, it was found that fuzes at -22°F would freeze water at 55°F in the ports almost instantly, and 20 seconds passed before the water began to flow into the space above the diaphragm. The tests were made at a pressure of only a few pounds per square inch, and the results may be affected markedly by the peak pressure of several hundred pounds per square inch encountered at normal entry velocity. As suggested by the Naval Ordnance Laboratory, it is possible that plastic insert ports may aid appreciably by retarding the rapid flow of heat from the water to the adjacent cold walls of the fuze. No field tests of the fuze or of the suggested modification have been made at low temperature.

Requirement 13 is not difficult to meet with a sealed fuze, especially if it is temperature-compensated. The action of the bellows operating against a spring load instead of its own elasticity prevents the bell cranks from starting to open until the arming pressure is nearly reached, as noted previously. With an arming pressure of about 9 lb/in.^2 minimum, no inward motion of the bellows or bell cranks will occur at the lowest temperature specified, even without compensation, if the fuzes are sealed at about normal room temperature. This means also that the safety wires could be withdrawn or inserted readily at low temperature. However, very low temperatures are generally encountered in rounds carried on aircraft at considerable altitude, and a tendency to arm spontaneously is overcome by the reduction in atmospheric pressure acting on the outside of the bellows of a sealed fuze. If very low arming pressures were to be specified for some special applications of rounds released from aircraft, the tendency to arm or partly arm spontaneously might have to be taken into account, especially if the rounds attained a high terminal velocity in air.

The satisfaction of Requirement 14 is primarily dependent on how long the fuze time constant may be made without increasing the arming depth appreciably over the specified maximum of 25 ft. While the fuze cavity volume was about as great as possible within the present fuze dimensions, the port hole diameter could be reduced if necessary to prevent prematures. The last and least desirable alternative would be to divide the design into two groups with different arming pressure, the higher arming group to be used for entry velocity, for example, above 300 ft/sec.

Although field tests are quite incomplete, it has been found that among 11 of the new fuzes fired at 45° entry angle and 410 ft/sec water entry velocity in 7.2-in., 68-lb flat-nosed rounds, all fuzes armed and no prematures occurred. The fuzes were completely sealed, and the mechanisms had been selected for greatest sensitivity. There was no trace of moisture inside the fuzes upon examination following the test, and the bellows were undamaged, although they showed a slightly lower spring rate than when new. It is evident from these tests that at the prevailing temperature the fuzes would not premature at 410 ft/sec in the scatter bombs, which require the highest entry velocity among the proposed fuze applications; and because of the very much less weight and smaller diameter of these bombs it would be expected that the prematuring entry velocity would be considerably

in excess of 410 ft/sec. From the results of previous tests made with the large-bellows fuzes, it would also be expected that the new fuzes would not premature at 320 ft/sec in the 100-lb round-nosed bombs. In the current model of the Mk 52 bomb, however, the fuze recess is so large and deep that the new fuze would seat below the nose of the round. This surrounds the fuze nose with a large pocket of air which might be forced into the fuze cavity under 90° incidence entry conditions and cause prematures, since the air would pass through the fuze ports much faster than water. It may be necessary to modify the cavity of this bomb or to use a filler ring of some kind to reduce the air volume. What effect on arming is produced by having the outer surface of the fuze nearly flush with or recessed into a bomb nose is not known, but this mounting arrangement may aid in increasing the prematuring entry velocity.

To determine whether the time constant was so great as to delay fuze arming appreciably, as well as to establish the maximum arming depth to be expected in the full range of entry velocity of 7.2-in., flat-nosed rounds, the fuzes were dropped in 66.5-lb ASR rounds from just above the water surface onto $\frac{1}{4}$ -in. steel plates on the target, which was located at various underwater depths. By requiring that the fuzes be fired upon recovery from the plates, cases of delayed arming, due to an excessive time constant at depths exceeding the fuze static arming depth, can be discovered. The arming pressure of the sealed fuzes for this test ranged from 10.0 to 10.9 lb/in.² To determine arming depth as accurately as possible with the 11 fuzes available, a different target depth setting was made for each test. Beginning at 35 ft, followed by 30 ft and 27 ft, each of three fuzes arming at 10.8 to 10.9 lb/in.² was recovered armed and fired. Two fuzes arming at 10.6 to 10.8 lb/in.² were armed and fired at depths of 25 ft. One fuze arming at 10.7 lb/in.² failed to arm at 20 ft. Two fuzes arming at 10.5 lb/in.² were armed and fired, one each at depths of 24 and 23 ft. One fuze arming at 10.6 lb/in.² was nearly armed but not fired at 22 ft, while another, arming at 10.3 lb/in.², was armed and fired at that depth. One 10.1-lb/in.² fuze armed and fired at 21 ft. It is evident that under these test conditions the fuzes were arming at slightly less than their static arming depth, probably because of the small dynamic pressure built up on the nose of the round at terminal velocity, and therefore the maximum time constant has not been reached in the present design. It is probable, however, that the same fuzes mounted in round-nosed, fast-sinking contact charges such as the Mk 12 would have shown some increase in arming depth over the static value.

Another field test was made to determine the approximate arming depth of the sealed fuzes when fired in 7.2-in., flat-nosed, 63-lb rounds at an entry angle of 45° and entry velocity of 175 ft/sec, against $\frac{1}{4}$ -in. steel plate at various target depths. Among three fuzes, one with an arming pressure of 10.9 lb/in.² and the other two at 10.7 lb/in.², fired at a 20-ft-deep target, the first one was recovered fully armed but not fired, while the other two were both fully armed and fired. Of four fuzes having arming pressures of 10.9, 10.7, 10.6 and 10.5 lb/in.² and fired at an 18-ft-deep target, all were recovered fully armed and fired except the first one, which was partly armed and not fired. Of two fuzes having arming pressures of 10.9 and 10.4 lb/in.², fired at a 17-ft-deep target, the shutter of the first was nearly freed by the bell cranks and the firing pin was released, while the

other fuze was recovered fully armed and fired. Of two fuzes having arming pressures of 10.8 and 10.5 lb/in.² and fired against a 16-ft-deep target, the first was recovered fully armed but not fired, while the other fuze was both fully armed and fired. One fuze arming at 10.7 lb/in.² and fired at a 15-ft-deep target neither armed nor fired. The last fuze arming at 9.9 lb/in.² in a round fired at a target 14 ft deep was recovered fully armed but not fired. The tests show that in these rounds the dynamic pressure wave at water entry is arming fuzes of 10.7 lb/in.² or lower arming pressure at depths of 18 ft or less, and that 10.9 lb/in.² slightly exceeds the peak of the transmitted pressure wave within the cavity. A wide variation in arming depth will therefore be encountered among fuzes differing by only a few tenths of a pound per square inch in arming pressure, at entry velocity such that the peak value of the pressure wave transmitted to the cavity falls within the normal spread of static arming pressure; the same effect will hold for fuzes having identical arming pressure but differing slightly in cavity volume. For instance, in these tests a fuze which armed statically at 10.5 lb/in.² armed at a depth of 16 ft, while most fuzes arming at 10.9 lb/in.² would have to descend to within a foot or two of the depth corresponding to the static arming pressure (in this case to about 23 or 24 ft); thus, a difference of only 0.4 lb/in.² would result in a change in arming depth of about 8 ft. This effect demonstrates one reason for a very close control of arming pressure, cavity volume, and port hole size during manufacture. However, at entry velocity exceeding the relatively narrow critical range, the fuzes will arm uniformly in the dynamic pressure wave, with little difference in arming depth in spite of the variations in static arming pressure, while at velocity below the critical range the fuzes will arm very consistently at somewhat less than their static arming pressure, except in the fast-sinking, round-nosed charges, in which a short time lag may be evidenced. Since the width of the critical entry velocity range with any given round depends to a large extent upon the fuze manufacturing variations, it may be made relatively narrow and, if of sufficient importance, perhaps moved by a slight change of fuze design into a range not used in service applications.

7.039. CONCLUSIONS.—A large number of tests obviously remain to be made before the design can be considered complete. It will be necessary to determine the minimum prematuring entry velocities at the most critical entry angles when the fuze is mounted in the actual rounds with which it is to be associated, using fuzes selected for the combined maximum sensitivity and minimum arming pressure and cavity volume that can occur in production with certain tolerance accumulations. Margins over prematuring at the specified maximum velocities may be determined in the final design, by lowering the fuze arming pressure with a weaker firing spring and using a spacer inside the fuze nose to reduce the cavity volume by a known amount. Most of the effects of temperature changes on uncompensated sealed fuzes may be duplicated at normal temperatures by substituting firing springs of different strength to bring the arming pressures to calculated values. The minimum service temperature of the fuze, established by water freezing in the ports, will need to be determined and means of lessening this effect investigated. One sample of the fuze has passed the three-position jolt test successfully, but no jumble tests have been made. From some tests made with the original bellows

fuze having greater effective mass of the arming mechanism and very weak firing springs, it is expected that the present fuze will show an ample margin of safety against prematuring in the Hedgehog. Additional safety drop tests on nose and side are necessary over a wide temperature range to establish the fuze safety in greater detail, and it is expected that the fuzes having die-cast head and base will be rejected. The fuzes used for the recent tests were made without a guide pin, in order to eliminate another possible source of air leaks, but since a lock would be necessary in production, where the magazines may not be tightened carefully, the pin could be either extruded from the body wall without leaving a through hole, or made as a fine-threaded screw with a positively sealing head passing through the body. The latter arrangement offers an additional advantage in providing an opening to the interior of the fuze which would enable pressures to be equalized, thus allowing the use of cement or lacquer on all the magazine threads, and allowing leak tests of all joints except the test hole to be made on the fuze after final assembly. The assembled loaded fuzes could be kept from arming by means of the safety wire when testing for bellows or mounting-ring leaks. During assembly the screw would be inserted temporarily, in order to prevent the fuze base from twisting if the tetryl disk tends to rotate the base as the magazine is tightened. Numerous sealing tests to determine the effects of different temperature expansion coefficients of the three metals forming the seal around the bellows mounting flange will have to be made, although no leaks at 90 lb/in.² air pressure were found in two samples of the present design when the fuze temperature was carried beyond both specified limits.

It is believed that the proposed modification of the Mk 140 with suggested improvements will result in a satisfactory pressure-arming fuze having many applications because of its versatility. It functions well over a very wide range of entry velocity, and because of the small diameter and projection of the nose in front of the round in which it is mounted the fuze can be faired readily into the noses of the newer types of fast-sinking contact charges. On the other hand it is true that the mechanism itself, with the large tolerance accumulations possible, is rather unsatisfactory from either a production or design standpoint, perhaps inherently so. A better fuze, offering the possibility of firing on an impact occurring within 1 ft under the water surface but free from prematures at normal entry conditions, might be produced by adapting a pressure-arming mechanism to the firing assembly of the Mk 156 and Mk 158 fuzes.

7.04. UNDERWATER VANE-ARMING FUZES, MKS 131, 136, 156, AND 158

Ammunition in which used

MK 131 AND MK 156 FUZES—ROCKETS FOR SHIPBOARD USE

7.2-in. Rocket Mk 6, with 2.25-in. Motor Mk 3 and mods (except Mod 1) (Mk 3 grain) and 7.2-in. Head Mk 4. Total nominal weight of rocket, 62.5 lb, TPX-filled.

7.2-in. Rocket Mk 7, with 7.2-in. Head Mk 5, otherwise same as 7.2-in. Rocket Mk 6. Total weight, 61.4 lb.

7.2-in. Rocket Mk 9, with Mk 10 grain; TNT-filled; otherwise same as 7.2-in. Rocket Mk 7; weight 57.5 lb.

MK 136 AND MK 158 FUZES—PROJECTOR CHARGES FOR SHIPBOARD USE

7.2-in. Projector Charge (Hedgehog) Mk 2, with PC Head Mk 4A and 2.25-in. PC Tail Mk 4A or Mk 4 Mod 1, having smokeless powder charge SPDN 3674 or 2951. Total weight, 65 lb, TNT-loaded.

7.2-in. Projector Charge (Hedgehog) Mk 3. Same as Mk 2, except TPX-loaded, with total weight of 68 lb.

7.2-in. Projector Charge Mk 5, with PC Head Mk 4 (except Mk 4A) and 2.25-in. PC Tail Mk 6, having 25.7-gm smokeless powder charge SPDN 3674. Total weight, 68 lb.

Dimensions and weight

The over-all dimensions, weight, and mounting-thread details are given in the outline drawing (Fig. 111).

Materials

Steel is used for the arming vane assembly, arming screw, plug, firing-pin sleeve, stops, and as an alternate with brass, for the body. Brass is used for the setback collar, weight, retaining ring, shutter, lead-in disk, and, as an alternate with steel, for the body. The firing pin is either steel or stainless steel. The magazine is made of die-casting alloy.

Explosive components

Detonator: instantaneous

Lead-in: tetryl

Booster: tetryl

General arrangement drawings

Mk 131: BuOrd Drawing No. 328804

Mk 136: BuOrd Drawing No. 330845

Mks 156 and 158: BuOrd Drawing No. 438552

7.041. GENERAL.—The original Mk 136 fuze was a very close duplicate of the British No. 420 fuze, as both were intended for use in Hedgehog projector charges. The Mk 131 was identical with the Mk 136 except that the former fuze omitted a setback collar shear wire, since rocket acceleration is negligible compared with that of projector charges. The Mks 156 and 158 are similar respectively to the Mks 131 and 136; they incorporate numerous changes found necessary after extensive tests, but the operating principles remain the same. Because of their simi-

larities the Mk 131 and Mk 136 can often be treated as a single fuze, in which case they will be referred to simply as the Mk 131-136. Likewise, when similar considerations apply, the Mk 156 and Mk 158 will be designated together as the Mk 156-158.

The fuzes are of the familiar inertia-firing type, sensitive to side and nose impacts of the round on the steel hull or wooden decking of a submarine. Arming is accomplished in two steps: first, acceleration on firing of the rocket motor moves the setback collar back against the plug shoulder; the vane assembly is unlocked by this motion, but is prevented from turning during air flight by the radial shear wire. Second, at the instant of water entry the radial wire is severed, and the vane assembly then rotates into its fully *armed* position after a short distance of underwater travel.

7.042. MECHANICAL DESIGN.—The fuze is designed around an inertia-firing assembly; this comprises a spring-loaded firing pin, retained by three locking balls which are positioned in a firing sleeve and surrounded by a striker head. This assembly is contained within the fuze body under pressure of the sleeve spring; while the fuze arms, this spring moves the entire assembly forward a distance somewhat greater than that necessary for the firing pin to release the spring-driven, detent-locked shutter. The assembly is maintained in the *unarmed* position and permitted to move forward by the arming screw, which is screwed outward by rotation of the vane, only after the fuze enters the water. The remainder of the fuze mechanism is essentially for the purpose of providing safety features.

The weight is retained in place by a restoring force derived from a component of the firing-spring compression acting through the locking balls on a conical surface inside the weight. In the *armed* position the weight is free to escape from the firing sleeve by rocking on a point around the circular base for sidewise impacts in any direction, and by moving forward in an axial direction for nose-on impacts. Independent adjustment of lateral and axial fuze sensitivity is possible by changing the weight center of gravity forward from the base, and by altering the base outside diameter.

The arming mechanism consists of a threaded shaft with rounded end, bearing on the weight to lock it in the *safe* position. The shaft is driven by a vane assembly of four blades set at a 20° angle, projecting far enough ahead of the mounting flange to avoid the radially moving water immediately in front of the projectile face during underwater flight. The vane assembly is prevented by the radial shear wire from rotating and arming the fuze during air flight of the projectile. When on the launcher with the safety wire withdrawn, the fuze is normally maintained in the *unarmed* position by a slot in the setback collar which engages two locking pins, one in the plug and one in the vane hub, preventing vane rotation. The collar is maintained in its forward, locking position by the collar shear wire in the Mk 158 fuze, but only by friction of the spring plate pressing against the locking pins in the Mk 156. Forward motion of the collar at water impact, when it could interfere with vane rotation, is prevented by the detent action of the spring plate as it drops behind the plug locking pin upon setback as the round is fired. After arming, the fuze is supposed to be kept watertight by the rubber sealing washer, which is squeezed between a recess in the fuze plug and the sealing collar

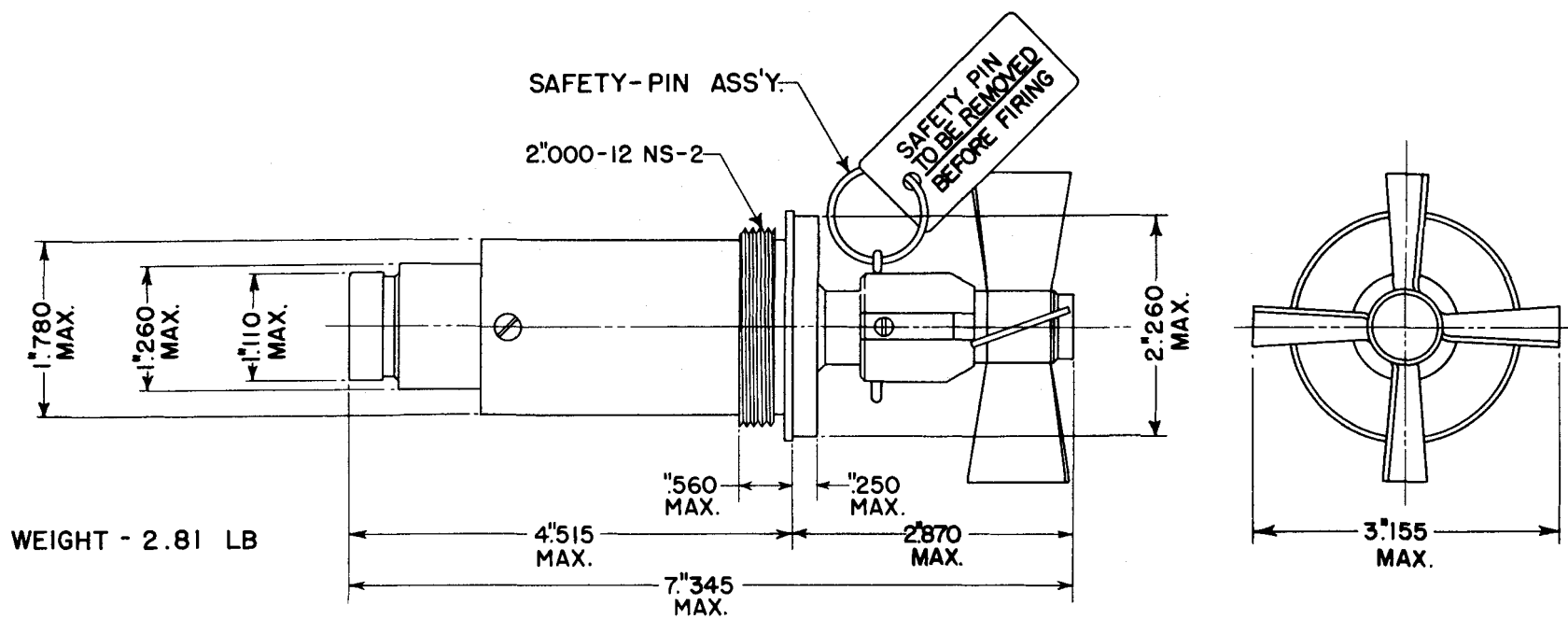


FIG. 111. Outline view of Nose Fuzes Mk 156 and Mk 158.

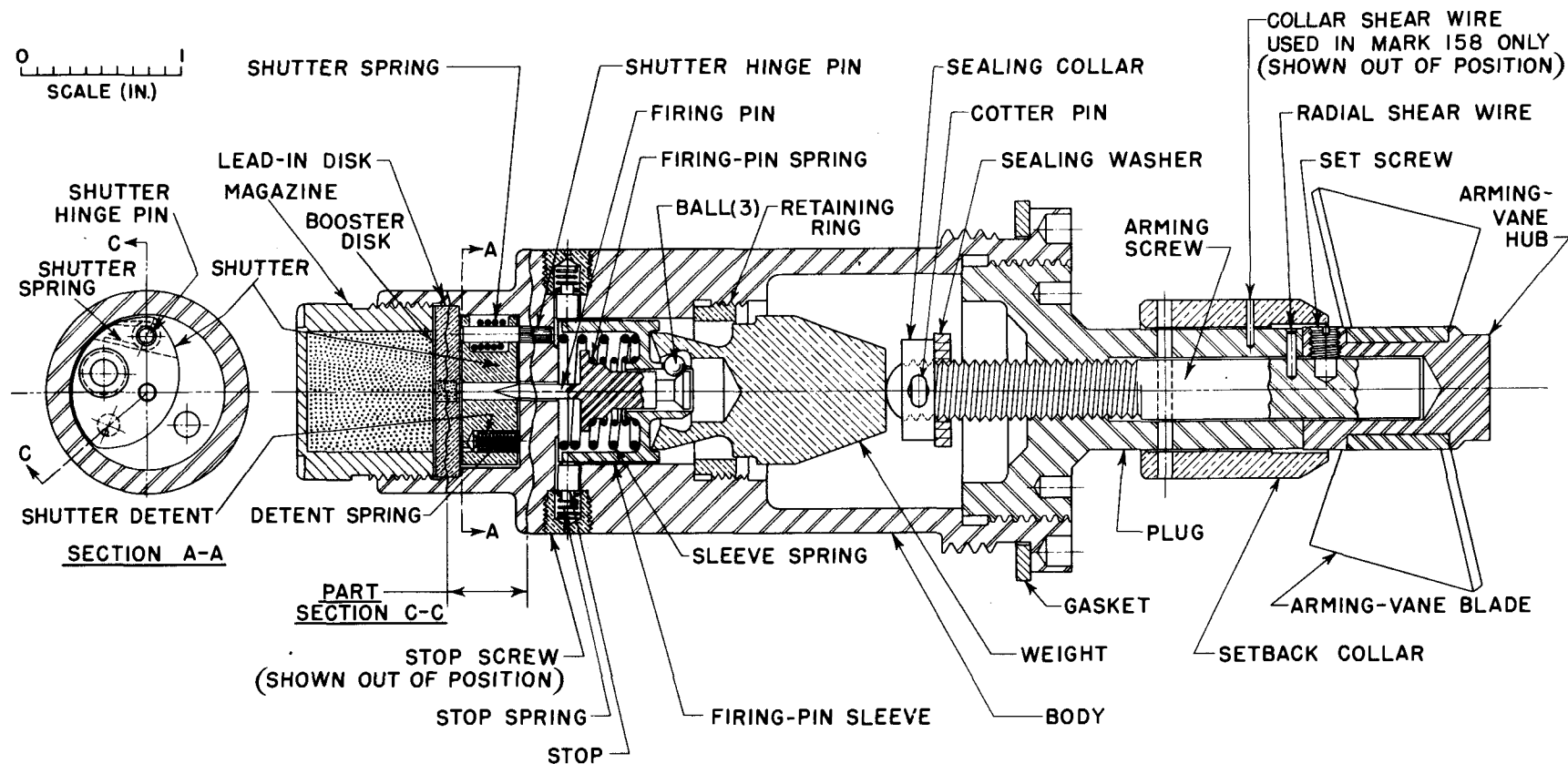


FIG. 112. Nose Fuzes Mk 156 and Mk 158, unarmed.

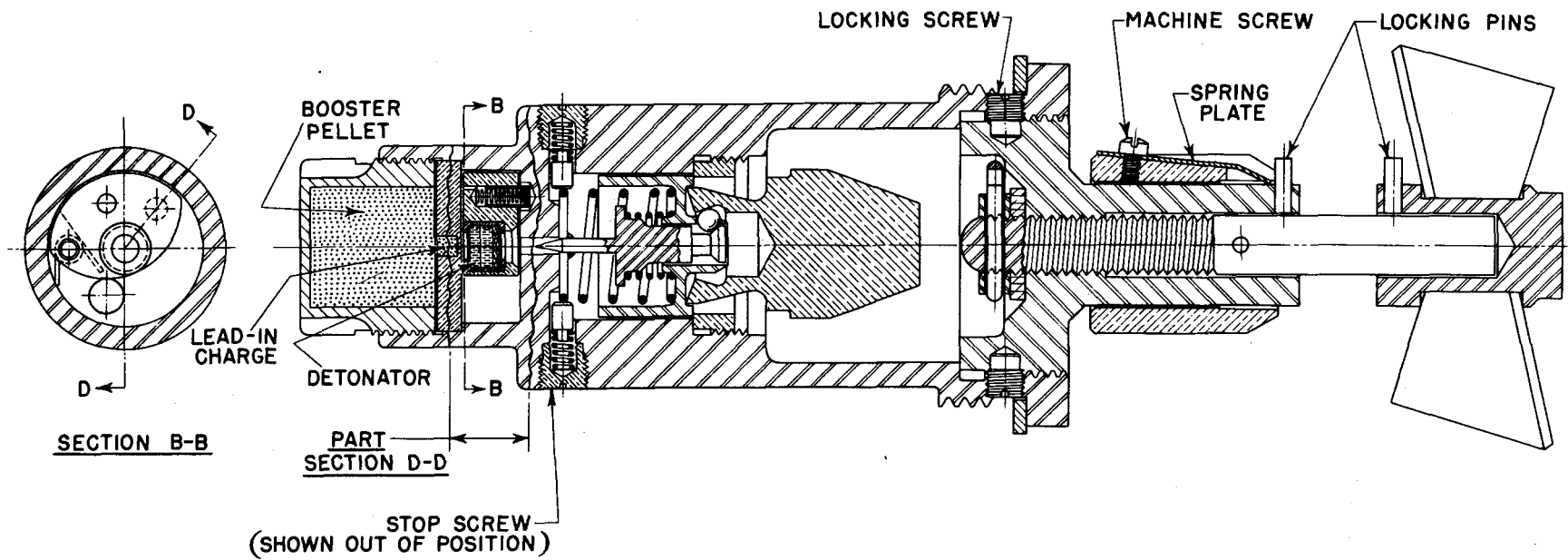


FIG. 113. Nose Fuzes Mk 156 and Mk 158, armed, turned 90° from Fig. 112.

mounted on the arming screw as the screw completes its forward travel. Left-hand threads are used on the arming screw to prevent any possibility of vane torque unscrewing a fuze inadvertently left not tightened in the projectile.

7.043. SAFETY.—The fuze is detonator-safe, since in the *unarmed* position the detonator is located away from the tetryl lead-in, over a safety vent hole leading to the fuze interior. A safety pin passing through the setback collar, fuze plug, and arming screw renders the fuze safe during transit and storage. Two locking screws passing through the body and into the plug prevent unintentional arming of the fuze by unscrewing the plug out of the body; attempts to remove a badly rusted fuze from a service round caused at least one serious accident before the screws were added.

When the fuze is unarmed it readily passes the safety drop test, since the firing pin is alongside the shutter, and the tetryl lead-in cannot be initiated from low-velocity penetration by the firing pin. Furthermore, arming requires that external parts of the fuze move forward relative to the body in a direction opposite to that of impact deformations, in contrast to the Mk 140. On side drops the weight is restrained both by the arming screw and by an outside shoulder which fits rather closely within the retaining ring. Difficulty in meeting the nose-on drop test was encountered among some Mk 131 and 136 fuzes in which the arming screws and plug necks were broken out of fuzes by the impact, allowing the firing assembly to move forward, arm the shutter, and fire the fuze. Strengthening the plug and body enables the Mk 156-158 to pass the drop test even at a temperature of -20°F . Collapsing of the long, slender arming mechanism projecting 2.87 in. in front of the face of the round is very effective in reducing the impact deceleration on nose drops to values tolerated by the rest of the fuze, and it protects the fuze in a manner somewhat similar to the protective cup of the Mk 140. The test specifies a 25-ft drop in a 65-lb round, and the appearance of fuzes dropped at low temperature indicates that this is close to the maximum impact to be withstood safely.

The stops and associated springs form another safety measure. There are four stops, alike in pairs, acting as detents under the firing-pin sleeve as it moves forward. One pair drops into place just before, and the other pair just after the shutter is released by the firing pin to rotate into the *armed* position. The stops make it possible partially to disarm an accidentally armed fuze by slowly turning the arming screw inward, which locks the weight without allowing the firing pin to contact the detonator. However, this procedure is not recommended unless it is certain that the fuze has not been subjected to mechanical shock subsequent to arming, as a "half-fired" fuze may be induced to fire by the inward rotation of the arming screw. The fuze tolerances are such that on relatively small shocks having low axial deceleration components, it is usually possible for the weight to lie over against the fuze body in any of three positions, symmetrical with respect to the three locking balls, without quite releasing the firing pin. A few "half-fired" fuzes will fire spontaneously after a delay of 1 sec to 10 min, but all are sensitive to any disturbance of the weight. The Mk 156-158 fuze did not incorporate the design changes and tolerance modifications to prevent this action.

After the round is placed on the launcher or projector and the safety pin withdrawn, the setback collar and vane shear wire are relied upon to maintain the fuze

safe from arming, even if heavy seas breaking over the round should impart torque to the vane assembly. The setback collar which engages both locking pins in a close-fitting slot was originally intended to perform this function by itself, and does so in the Mk 158. However, the very low acceleration of rocket motors at low temperature, coupled with the wide variations (measuring 7 to 1) in force required to move the collar back in the Mk 131 and 156, made it necessary to issue instructions to retract the collars manually at temperatures lower than 50°F. This leaves the radial shear wire (0.051-in. phosphor bronze) as the only restraint against rotation of the vane by heavy seas, and tests have shown the wire to be safe at speeds up to 28 knots, relative to the water passing the vane. Before removal of the round from the launcher, the setback collar is restored to the *safe* position and the safety pin inserted.

An important safety feature of the fuze is that an armed or partly armed fuze is readily detected at a distance by visual inspection of the gap between the plug and vane hub which forms as the fuze arms. The extent of arming also may be estimated by inspection, determining the most effective procedure to be followed in safely disposing of the round.

7.044. ARMING.—The radial shear wire is severed at virtually the instant the vane strikes the water at an entry velocity above about 62 ft/sec. From an average of 24 measurements made on production Mk 156-158 fuzes, the first and second pairs of stops drop into place beneath the firing sleeve 1.7 and 2.2 vane revolutions, respectively, after radial shear wire severance, followed by shutter release at 2.8 revolutions. Although this sequence is not as originally intended, the fuze is safe by about 0.050 in. if disarmed by rotating the arming screw in the reverse direction, since this forces the firing sleeve back against the stops. After a total of 4.4 vane revolutions the firing sleeve comes into contact with the retaining ring, preventing further forward motion of the assembly and permitting the arming screw to lose contact with the weight. A gap between the weight and arming screw is formed by further turning of the latter, to allow axial escape of the weight on nose impact. The sealing collar comes to rest against the sealing washer after total vane revolutions varying between 7.2 and 7.9, representing a maximum of about 24 ft of underwater travel when the fuzes are fired in ASR rounds with 10° tail fins. The fuzes are armed for sidewise firing when the arming screws have made a total of between 4.0 and 5.7 revolutions, depending on the strength of impact, since the backward freedom of motion of the firing sleeve will allow a fuze to fire slightly before the arming screw loses contact with the weight, although with less than normal sensitivity. Four to 5.7 revolutions correspond to underwater travel distances of about 10.5 ft to 16.5 ft. Arming for axial firing is completed after about 6.8 revolutions, corresponding to 20 ft of underwater travel in ASR rounds with 10° fins. These figures are subject to small variations, of course, due both to fuze tolerances and to projectile yaw conditions at water entry.

In the Mk 131-136 fuze the shutter was held against a stop pin by the driving spring when in the *armed* position, but was not secured by detents. On sidewise impact in a direction to swing the shutter away from the stop pin by the inertia forces, misfires were frequent, as the detonator was out of alignment with the firing pin by the time the fuze fired and the pin was released. It was found that

occasional misfires from this cause occurred when fuzed rounds were dropped under water against the slant plate, even at impact angles of only 15°. To overcome this defect the shutter in the Mk 156-158 fuze was provided with a locking detent.

7.045. FIRING.—The firing of the fuze is effected in the same manner as in the Mk 135, by escape of the weight either forward or sidewise past the three locking balls, releasing the firing pin. For forward firing, the initial motion of the weight forces the locking balls inward, lifting the firing pin and further compressing the firing spring until the minimum inside diameter of the weight passes the center line of the balls. The added maximum compression of the firing spring averages 0.028 in. when the weight has moved forward off the firing sleeve a distance of about 0.080 in., and the firing pin is released by a total weight motion of about 0.143 in. on the average. For sidewise firing, in which the weight rocks on a point on its base, the added firing-spring compression averages only 0.021 in. The fuze is sensitive to wooden-deck impact, but an appreciable percentage of failures are encountered at terminal velocity on the span center, and the action is more variable than that of the Mk 135 and the modified Mk 140 because of (1) the distance the fuze projects ahead of the round and (2) the variable strength of the vane assemblies. The sidewise sensitivity is exceptionally good, the fuzes firing consistently on slant plate impact angles of only 15°.

7.046. FUZE MODIFICATIONS.—The first lots of Mk 131 and 136 fuzes duplicated the British design in specifying a 0.032-in. copper vane shear wire, and vane blades curved along the lower edge to increase the speed of arming. The vane shear wire refers to the location of the short, straight wire severed by initial vane rotation, which in all the Mk 131 and 136 fuzes was positioned half in the vane hub and half in the plug, in matching holes drilled parallel with the fuze axis. The wide variations in force required to retract the setback collars of the Mk 131 fuzes and the small values of acceleration from rocket motors at low temperature led to changing the vane shear wire to 0.051-in. phosphor bronze in order to avoid accidental arming when the collars were retracted manually at temperatures below 50°F. Recurring reports of prematures among salvos of the British No. 420 fuze resulted in adopting the British modifications of flattening the vane blades and changing the firing springs to a design less overstressed and therefore less subject to weakening due to aging in the compressed position. It is not thought, however, that either of these factors was responsible for the occasional prematures reported for the U. S. fuzes.

The acceptance tests of the Mk 131 and 136 fuzes, performed in part by CIT under Navy specifications, showed that a large number of arming failures were occurring, averaging 28 per cent among Mk 131 fuzes which were tested at entry velocities of 130 and 190 ft/sec, and 19 per cent among the Mk 136 fuzes tested at velocities of 130 and 150 ft/sec. The number of failures varied widely among the different groups of lots received for test, sometimes averaging as high as 40 per cent. The reasons for the unsatisfactory performance were completely obscured by damage to the arming mechanism sustained upon impact against the ¼-in.-thick plates at the target depth of 20 ft, which was specified in the testing procedure. A large number of fuzes for experimental purposes only was requested and received ;

when these were tested with the line-and-spring methods, the failures were shown to be due both to shear wire interference and to damage to the vane assembly sustained upon water impact at entry. Shear wire interference describes a curious action of the two sheared halves of the wires which, immediately following severance, emerge from their containing blind-drilled holes under water pressure as far as the opposite shearing surface allows, locking together on either the first or second revolution of the vane and preventing further arming. This difficulty was especially serious since it did not simply delay arming but prevented it altogether, regardless of the distance of underwater travel. The second factor took the form either of stripping off one or more of the silver-soldered blades or of bending the blades into a zero-torque position. Bending of the blades was found to be more serious than losing them, since lost blades merely failed to contribute to the driving torque, whereas bent blades absorbed the torque required to rotate them through the water. Damaged vane assemblies were not so serious as shear wire interference, since fuze arming was delayed but not entirely prevented. Trial of several methods for preventing shear wire interference led to cementing both ends of the wire in the containing holes, as this could be done readily with the thousands of fuzes already manufactured. No modification of the vane assemblies was made. Although cementing of the wires was not done with uniform care by the manufacturers, the percentage of fuze failures in the acceptance tests dropped to an average of 17 per cent and 4 per cent for the Mk 131 and 136 fuzes respectively. The difference was due to the larger forces (resulting from the higher entry velocity) which act on the vanes of the Mk 131. From a large number of tests made with fuzes having strengthened vane assemblies and the arming shear wire changed to engage the plug and arming screw radially, it was clear that virtually 100 per cent arming of the fuzes could be expected with these two improvements; therefore, they were incorporated into the Mk 156-158 fuzes along with several other less important changes.

7.047. FUZE TESTS.—Approximate determinations of some characteristics of the Mk 156-158 fuze have been made by relatively crude field tests and measurements, intended to provide essential operating data within the wartime limitations of time, facilities, and personnel, and are grouped into the three main divisions of fuze behavior—arming, firing, and prematuring.

7.0471. ARMING: SETBACK COLLAR.—The first step in arming is the retraction of the setback collar as the propelling motor is fired. As noted previously, the mechanical design of the collar is satisfactory for the Hedgehog rounds for which it was originally intended, but rocket accelerations essentially require a different mechanism altogether. There is a wide variation in force required to retract the collar, ranging from 5 g to 35 g in a large number of measurements, usually due to friction differences in the spring plate which rests on the locking pins. Smoother and more reproducible action can be obtained if the collar is retained in the forward position by spring force rather than friction; in addition greater safety is provided, since the restoring force of a spring returns the collar to its original position if there is any accidental acceleration or series of shocks or vibrations less than the value necessary to move the collar into its entirely retracted position. However, any sensitive setback mechanism for rocket fuzes should be enclosed within the fuze as protection from corrosion, dirt, and accidental deformations in

handling, all of which reduce the ratio of accurate spring control to variable friction forces. It is also true that a mechanism which will operate consistently on rocket motor accelerations of only 5 g will be responsive to shocks from other sources aboard ship transmitted to the launchers, and must therefore be of the self-restoring type for safety. However, this type cannot be employed in the underwater vane-arming fuze, since no other arming action, such as rotation of an air propeller, takes place during the acceleration period, and the self-restoring setback would therefore prevent the fuze from arming after water entry.

One method proposed for improving the operation of the setback collar of the Mk 131 was to provide a flange around the base which would tend to force the collar back upon water entry. Tests of the device showed first that the flange should be located at the top of the collar to avoid the radially moving water in front of a flat-nosed round, and second that the large deceleration at water entry nullified the backward force of the water on the collar. Flanged collars made entirely of Dural to avoid inertia action overcame the deceleration difficulty, but locating the flange behind the vane inherently gave the wrong arming sequence, since vane torque always preceded the water thrust (on the collar) which was expected to unlock the vane. Frequent arming failures, and the probability of collars being forced back by heavy seas breaking over rounds in the launchers led to dropping the design.

It will be noted that the measurements of force required to retract the collar indicate that some fuzes would fail to arm even in rockets at ordinary temperatures, and tests have shown that about 10 per cent of fuze collars in the Mk 156 are not fully retracted by rocket motor acceleration at 40°F. That the fuzes do arm in spite of this is due to an accident in design involving fuze tolerances, whereby the upper end of the spring plate does not extend beyond but rests on top of the vane hub locking pin. The force required to move the collar back until the end of the plate slips off the plug pin and drops down between the two locking pins is not very great, but further backward collar motion gives the maximum peak of setback force required, since the plate with its high spring rate must be lifted over the top of the plug pin, and burrs around the edges of the pin dig into the under surface of the plate. However, the small backward motion of the collar which lets the plate drop between the locking pins usually brings the top of the collar nearly even with the center of the vane hub locking pin, so that the large water entry torque can force the pin out of the partial collar engagement and allow the fuze to arm. In water-firing tests of 144 standard Mk 156 fuzes using 62.5-lb rounds with Mk 3 motor and Mk 10 grain at 40°F, all fuzes were fully armed at a target depth of 25 ft, although 27 collars failed to retract beyond the plug locking pin, as evidenced by the damaged lips of the slots in the brass collar covered by the spring plate.

7.0472. ARMING: SHEAR WIRE.—Static measurements of the torque required to sever the axial vane shear wire of the Mk 131-136 fuze gave an average value of 44 in.-lb, but there was a wide variation, due to the frequently wide spacing between the vane hub and end of the fuze plug which formed the shearing surfaces. It has been observed that in fuzes with extreme spacing the shear wire may be pulled out of one or the other hole without shearing. The radial shear wire of the Mk 156-158

fuze overcomes this difficulty and provides a relatively uniform shearing torque, since the spacing of the shearing surfaces is very small and uniform. The shearing torque of the present fuzes averages 26.5 in.-lb and is so much lower than the 35.5-in.-lb average value obtained when phosphor-bronze wire is used that it is possible that copper wire may have been substituted in manufacture. The lower shearing torque of the radial as compared with axial shear wire is due both to the greater lever arm and to the greater average separation of the shearing surfaces in the latter position, and may be brought back to a value about 8 per cent greater than the axial shearing torque by using 0.057-in. instead of 0.051-in. phosphor-bronze wire.

The minimum entry velocity to sever the axial shear wire of the Mk 131 and 136 fuzes was found to lie between 62 and 80 ft/sec at entry angles of between 20° and 90°, measured from the horizontal. If the assumption is made that the shearing torque varies with the square of the velocity, the static shear measurements taken with production Mk 156 and 158 fuzes indicate that the minimum entry velocity range for the modified fuzes should be from 48 to 62 ft/sec. These figures establish the minimum entry velocities necessary for possible applications of the present fuze.

7.0473. ARMING: UNDERWATER VANE SPEED.—The bending and locking of the arming screws upon impact with the horizontal $\frac{1}{4}$ -in. steel plate target, observed during acceptance tests, offered a ready means for determining the fuze "arming rate" or feet of underwater travel of the round required for each revolution of the arming screw. The target was set under water at depths of 5, 7, 10, 12, 15, and 18 ft, and the rounds fired at entry velocities of 130 and 190 ft/sec and at an entry angle of 45°. The fuzes were of the standard Mk 131 type, except that the vane shear wire was carefully cemented and the vane blades had heavily filleted welds; these blades were known not to deform at entry velocity of 190 ft/sec. The rounds were fired with the setback collar manually retracted. Upon recovery from the target, the fuzes having a securely locked arming screw were disassembled and the plug neck sawed through near the top to free the screw. The revolutions of the vane down to the particular target depth could then be counted accurately by turning the arming screw back until the safety-wire holes were aligned, since the holes were drilled individually through each fuze at manufacture. The results at each depth and entry velocity were in unexpectedly good agreement, and when plotted as vane revolutions against target depth the points lay closely along two straight lines of only slight divergence, corresponding to the two entry velocities, which, when extrapolated to depths shallower than the minimum possible test depth of 5 ft, passed through the origin. The divergence between the two velocities amounted to no more than 0.4 revolution at a depth of 18 ft. The "arming rate" at 130 ft/sec was 3.5 ft of underwater travel per turn, while that at 190 ft/sec was 3.3 ft per turn. Since the lines passed through the origin, there is apparently no appreciable delay in accelerating the vanes to an average rotational speed of about 1700 rev/min over the first 12 ft of underwater trajectory distance.

A few tests were made with Mk 131-136 fuzes to determine the arming depths under other conditions. If fuzes which are standard except for omission of the vane shear wires are mounted in ASR rounds with 10° tail fins and dropped nose-down from 3 ft above the water, the fuzes will arm four turns at a 10-ft depth and will

fully arm at 15 ft. Under these conditions the fuzes, as would be expected, will not sever a 0.032-in. soft copper vane shear wire at terminal velocity. In other tests the effect of bomb rotation under water was observed. Since this rotation is in a direction to assist in arming the fuze, tests were made of the arming depth of fuzes with vane blades mounted parallel to the fuze axis and without shear wire when mounted in ASR rounds and dropped nose-down as before from 3 ft above the water surface. The fuzes armed 1.25 turns at 40 ft, 3.5 turns at 50 ft, 6.5 turns at 65 ft, and were fully armed, 8 turns, at 75 ft.

The thickness of square-cut vane blades will affect the arming rate and thereby cause the straight-line graphs mentioned in the preceding paragraph to curve when rounds with such blades enter the water at normal velocities; this behavior is due at least partly to the squared leading edge of the blades. Vanes 0.125 in. thick instead of the original 0.062 in., but otherwise of standard dimensions, required a depth of 22 ft for 7.7 revolutions, and armed only 4.2 revolutions at a depth of 18 ft when used in ASR rounds fired at a 45° entry angle and 190 ft/sec velocity. An appreciable reduction in vane speed has likewise been observed in the Mk 156-158 fuzes, which have 0.093-in.-thick blades, also cut square across the leading edge, the new rate measuring about 3.7 ft of underwater travel for one vane revolution at 190 ft/sec entry velocity. It is probable that the vane speed could be increased by shaping the corner of the blade leading edge along the lift surface into a rough approximation to an airfoil edge, but this might not be warranted unless some evidence of arming instability were observed.

All the preceding tests were made with a stationary launcher located about 60 ft from the water-entry point of the rounds. Under actual service conditions, however, the rockets are rotating at measured speeds of between 3.2 and 4.8 rev/sec, with an average of 4.0 rev/sec or 240 rev/min at the end of their normal air flight just before entering the water. The direction of rotation, as noted before, will aid in arming the fuzes, but the effect is not marked under ordinary conditions. To duplicate service conditions and at the same time enable recovery of the fuzes on the available target, an electrically-driven rotary launcher was constructed to bring the rounds up to 250 rev/min before firing. Tests made with this launcher at 190 ft/sec entry velocity disclosed the presence of an entry transient in Mk 156-158 fuzes, which, by the time the round has traveled 9 ft under water, adds about 1.2 vane revolutions (equivalent to 50 per cent) to the value which would exist at that distance without spinning the round.

Between 5 and 10 ft the arming rate drops to 3.5 ft of travel for each revolution, only about five per cent greater than the rate with a round which enters the water without spin.

The possibility of arming a fuze having vanes parallel to the fuze axis by bomb rotation has been considered but does not appear practical for ASR application in spite of the obvious safety advantages on the launcher and elimination of a tendency to arm during air flight. Among the disadvantages, the outstanding one is the deep arming which would have to be accepted even if the lead of the arming screw were to be doubled—an arming depth of about 40 ft at 175 ft/sec and 45° entry is estimated.

7.0474. ARMING: EFFECT OF CORROSION.—One test to ascertain the effects of

salt water action on fuze functioning was made on 15 Mk 131 fuzes which were withdrawn from service in a severely corroded condition; these were of early design, with curved vane blades. The fuzes were mounted in ASR rounds, at a temperature of about 70°F, and fired into the water with a 45° entry against horizontal ¼-in. steel plates at a depth of 20 ft, eight at 130 and seven at 190 ft/sec. All fuzes armed and fired on the target, except one at 130 ft/sec, in which the setback collar did not move at all because of burrs around the safety-pin holes. The collars of three other fuzes fired at 130 ft/sec did not retract completely, but the vanes forced the hub locking pins past the collar slots, and the fuzes armed fully at the target depth. In all cases the high torque at water entry was sufficient to break through the extensive corrosion around the external arming mechanism. Examination of the internal parts of the fuzes revealed no corrosion beyond a superficial rusting of the first few arming-screw threads.

7.0475. FIRING: LABORATORY AND FIELD DETERMINATIONS OF SENSITIVITY.—Laboratory measurements involve two different methods of rating static fuze sensitivity. The total measured weight required to remove the fuze striker head in an axial direction, divided by the weight of the striker head, gives a roughly approximate value of the firing sensitivity expressed in *g* units. Determined in this way, numerous measurements on the Mk 131-136 fuzes gave an average of 36 *g*, with a maximum of 46 *g* and a minimum of 31 *g*. The Mk 156-158 fuzes measured an average of 32 *g*, with a maximum of 35 *g* and a minimum of 28 *g*. As a second test, the steel block sensitivity averaged 1.06 in. for the Mk 131-136 fuze and 0.94 in. for the Mk 156-158. To obtain consistency in the drop tests, the fuze plug must be removed and replaced with a rounded steel nose cap which screws into the inside body threads and must seat very firmly and evenly on the internal body shoulder just below the plug threads, and not on the external body shoulder. Steel block drops made with the fuze plug and arming mechanism in place do not differentiate among firing assembly sensitivities because of the variable resiliencies of the arming mechanisms themselves.

Field determinations of sensitivity were made under three sets of conditions that closely simulated those most probably occurring in service use:

1. The firing performance on slant steel plate is very satisfactory in the Mk 156-158 fuze, whereas the absence of a shutter detent in the Mk 131-136 fuze had caused numerous dud firings, amounting to 20 per cent in one test. The tests were made in ASR rounds striking the plate at terminal velocity. Since the fuzes are not well sealed against water under high pressure, a very severe test was made by completely filling inert fuzes with water and dropping them onto the slant plate. In this test all fuzes fired mechanically in ten drops with the plate 60° from horizontal, and a similar result was obtained in 14 drops with the plate 75° from horizontal.

2. For wooden-deck impacts at 23 ft/sec the results of over 400 tests made with ASR rounds at terminal velocity, concentrated as closely to the span center as the test method allowed, gave 12 per cent failures of the firing mechanism to function. All failures occurred within 5 in. of the span center. Seventy-six per cent of the failures occurred on single-batten impacts. The remaining 24 per cent took place when the impacts centered in the open space between adjacent battens;

in such impacts blades were stripped from the vanes, plug necks penetrated and wedged between battens, and deceleration was reduced below the firing level in spite of the contact with two battens. Of all failures occurring in single-batten impacts, 60 per cent were within 2 in. of the span center. Since these tests were made with fuzes having the Mk 156-158 vane assemblies, the per cent of misfires among Mk 131-136 fuzes under actual service conditions probably would be doubled because of vane damage and weakening sustained at water entry. However, since the test drops were concentrated near the span center, the per cent of misfires occurring at terminal velocity in service use, with random hits over the entire projected submarine surface, would be reduced to a very small value. (This conclusion is based of course on the assumption that the test deck reproduced impact conditions of the actual targets.)

A large number of other tests were made to investigate further the causes of the failures, so that the most effective improvements could be made. Within the limits of the present fuze design, the firing mechanism is insufficiently sensitive when some of the numerous impact variables combine to give low deceleration. Among the variables may be mentioned the two largest: first, difference in batten strength, which has been found to vary by a factor of two when measured in a standard materials-testing machine, although the battens are obtained to close specifications, and second, differences in vane strength. The latter variable involves the vane design itself, in addition to manufacturing variations, as the mechanism is entirely too weak to withstand and transmit the forces required to fire a 35-g fuze. This is well brought out by impacts centering in the 0.75-in. space between adjacent battens, especially if two of the blades enter the space, leaving the entire load to be carried by only two vanes. In such instances the two blades are stripped from the fuze, and the entire neck of the fuze plug enters the space between battens with a wedging action which lowers the deceleration below the firing level in spite of the 2-batten impact. However, it is also true that frequent failures have occurred on single-batten impacts because of blade stripping which allows the vane hub and plug neck to penetrate deeply into the wood. When batten penetration is combined with impact near a span center, a high percentage of failures will result. The use of blades 0.125-in. thick, heavily filleted in welding to the vane hub, gave a marked firing improvement, but the batten strength factor remained as an erratic variable controlling firing. Improving the fuze sensitivity to a 0.44-in. steel-block drop-test value, by undercutting the firing-pin head, increasing the external cone angle within the striker head from 20° to 30°, and weighting the striker head with lead will result in virtually 100 per cent firing at terminal velocity. The strength of the firing spring was not altered to gain sensitivity, since it is already often below the 9-lb limit usually specified for perfect detonator action, and also since the firing-pin velocity might become too low if a fuze should fill with water. The methods used to improve fuze sensitivity were for the purpose of obtaining experimental information only and are not intended to suggest a design change. Improved firing may be attained in a different manner described later.

3. For wooden-deck impacts at 16 ft/sec, which is the minimum underwater velocity of an ASR, the percentage of firing failures is greatly increased. For test

purposes a 16-ft/sec ASR terminal velocity is obtained by attaching a thin, 5-in. diameter retarding disk to the motor shroud. In a total of 45 drops with standard fuzes, excluding hits closer than 5 in. from a deck support, there were 16 misfires, equivalent to about 35 per cent.

It was determined from another series of underwater tests that at least for the 16-ft/sec velocity fuze firing could be ascertained with substantially equivalent results by leaving the deck in air, since water surrounding the battens did not contribute appreciably to their reaction. The rounds could then be dropped from a height of 4 ft above the deck for a striking velocity of 16 ft/sec. This simplification of procedure enabled all rounds to be dropped alike with sufficient precision to strike repeatedly any desired section of the target. In 96 drops with standard Mk 131-136 fuzes striking the center of the battens in the middle of the span, there were 29 misfires, equivalent to 30 per cent. The same fuzes were then modified by replacing the plugs with special flat face plugs which seated flush with the outside surface of the fuze body. This entirely eliminated the projecting arming mechanism, so that a minimum of two battens would be contacted almost simultaneously by the face of the round. To make the following two tests more severe the battens used were selected for minimum strength, determined both by density and from grain appearance, which had been found by testing-machine measurements as well as fuze firing tests to be reliable guides. In 24 drops from a height of 4 ft, with each fuze striking the center of a batten in the middle of the span, all fuzes fired. In 24 other tests using the same fuzes but with the deck rearranged so that each fuze struck the center of the spacing between adjacent battens, giving a maximum of 2-batten impacts, all fuzes again fired.

Two other air-drop tests were made to determine roughly the sensitivity margin of the same group of 24 flat-nosed fuzes. For each drop all battens but one were removed from the deck and the fuzed round dropped on the batten center. Using slats selected for minimum strength, there were eight failures, equivalent to 33 per cent, and with battens selected for maximum strength, there were two failures in 22 valid tests, equivalent to ten per cent.

As a final nose-on test, to determine the firing performance of fuzes having vanes which are jettisoned at the completion of arming (as suggested at one time by the British), the 24 fuzes were provided with standard plugs having setback collars with flush arming screws but without vanes. The fuzes were dropped in ASR rounds from 4 ft in air onto the centers of single battens selected for maximum strength. There were six firing failures, or 27 per cent, among the 22 valid tests.

A few tests were made of the sidewise sensitivity of the Mk 131-136 fuze dropped in ASR rounds that were suspended horizontally over the deck center at a height of 3 ft, as specified in parts of the Mk 131-136 acceptance tests not to be performed ordinarily by CIT. In 24 drops all fuzes fired mechanically, the rounds contacting four battens at once. In six tests the rounds were so oriented before dropping that the shutter could swing by inertia away from the stop pin; after recovery the shutter in all six fuzes was found alongside the firing pin, with the detonator not touched by the firing pin.

7.0476. PREMATURE.—There have been several instances reported by the

Navy of premature firing of the Mk 131 and 136 fuzes upon water entry. There are also on record similar cases of prematuring experienced with the British No. 420 fuze. The elimination of the curve along the lower edge of the vane blades to increase the arming depth slightly, and the substitution of a new firing spring to avoid gradual weakening from overstressed wire with resultant gain in firing sensitivity were two early modifications in both the Mk 131-136 and the British 420 to reduce the possibility of prematures. A third cause of prematures was found in local tests shortly after the first Mk 131-136 fuzes were received for making the water-firing portion of the acceptance tests. It was determined that if a stop spring becomes caught under the stop screw at assembly, it is possible for a stop to be forced tightly enough against the firing sleeve to hinder forward motion of the firing assembly as the fuze arms. If the sleeve is actually locked by the stop, tests show that a dud premature will always take place in ASR rounds fired at 190 ft/sec entry, will sometimes occur at 150 ft/sec, and may be possible at 130 ft/sec, depending on fuze tolerances. The reason for the prematures is the formation of a gap between the fuze weight and the arming screw immediately after water entry, which allows the weight to escape in a forward direction because of deceleration. The premature will be a dud, since the shutter is held in the *unarmed* position by the firing pin, which does not move forward as the round enters the water. However, at the two lower entry velocities, at which dud prematures may not occur, if the stop for any reason should release the sleeve subsequent to arming of the vane assembly, then a live premature will always occur as the firing assembly is snapped forward by the sleeve spring against the retaining ring. To avoid this hazard, production of Mk 131-136 fuzes was changed to incorporate a new stop design, since used for the Mk 156-158 fuzes.

It is believed that arming of the fuzes during air flight, resulting from severed or omitted shear wires, is the usual cause of prematures. A series of tests made on a land range using standard ASR at a QE of 45° with Mk 131-136 fuzes, some having a severed vane shear wire, and others having none, showed that at an air velocity of 156 ft/sec, measured at the end of burning, five in 28 fuzes were fully armed and fired at the end of the air trajectory, and two more were armed enough to premature just below the water surface in service use also—a total of 25 per cent. Under the same conditions but at 168 ft/sec maximum air velocity, 13 in 35 fuzes were fully armed and fired at ground impact, equivalent to 37 per cent. At 198 and 210 ft/sec air velocities, the percentage of completely armed and fired fuzes rose to 71 and 100 per cent respectively. When, as a test control, nine other fuzes were fired with unsevered shear wire to make certain that ground penetration by the round upon impact could neither fully nor partly arm the fuzes, in no case was the arming screw rotated more than one-fourth a turn. There were indications in the test that some fuze lots were more apt to arm in air flight than others, but a definite conclusion on this point would require more data. Examination of the fuzes after the tests, as well as of other fuzes from the same lots, did not reveal any appreciable difference to account for the air-arming action, and it is probable that slight friction variations usually offset the low vane torque. Since all rounds were fired from a single-rail launcher, no determination was made of possible blast effects from adjacent rounds during ripple firing.

Absence of the vane shear wire lock in fuzes may be due either to omission of the wires at assembly or to severance of the wires in assembly operations or in subsequent handling. In a group of 72 new Mk 136 fuzes of the final lots manufactured, while all wires were present, seven wires were found to be already severed when the fuzes were received. Among the remaining 65 fuzes it was possible to sever 14 manually by rotating the vanes as far clockwise and counterclockwise as the mechanism would permit, without forcing, with the safety pin removed but with the setback collar in the normal, fully forward position. The 14 wires probably would have been severed in service use if the safety pins had been removed and the fuzes screwed into or tightened in the rounds by grasping the vanes instead of using a wrench in the specified manner. Manual retraction of setback collars in the rocket fuzes at temperatures below 50°F is conducive to shearing the wires, since restoring the collars, necessitating lifting of the spring plates, is an awkward operation at best, especially if the plates are riveted to the collars. Probably the most serious difficulty is the fact that the position of the wires precludes visual inspection of their condition, and this situation remains in the Mk 156-158 fuze with the radial shear wire. Recent restrictions in the critical manufacturing tolerances of the Mk 156-158 are believed to avoid the possibility of severing the wire, so long as the setback collar is not retracted. It would appear advisable to incorporate some type of friction device to prevent air arming in the event a shear wire is severed—perhaps in the form of a small rubber ring, mounted in the forward end of the plug and fitting the arming screw snugly, although a protected location inside the fuze would be preferable. To avoid arming interference from excessive friction after the round has passed the high-torque position along the underwater trajectory, the arming screw may be undercut slightly so that the rubber ring is no longer in contact with the screw after the first two or three vane revolutions. It may be possible further to use the ring to provide water sealing at the end of arming screw travel rather than depend on the relatively poor seal afforded by the internal washer.

During hundreds of test firings made at Morris Dam, in which the rockets entered the water in the normal velocity range of 130 to 190 ft/sec after a short air flight, no prematures of the standard vane-arming fuze have been encountered. This is attributable of course to the principle of vane arming, which is simple, reliable, and very uniform in action. In order to induce prematuring, to learn more about its characteristics, and to establish the minimum practicable distance of underwater travel for fuze arming, tests have been made under three conditions—at high entry velocity, with partly prearmed fuzes, and with fuzes of more rapid arming rates. These tests are described in the following paragraphs.

7.0477. **PREMATURING TESTS AT HIGH ENTRY VELOCITY WITH NONROTATING LAUNCHER.**—Since arming rate is virtually independent of entry velocity, this type of fuze or arming mechanism should be very effective in avoiding prematures at high entry velocity. While only a few tests have been made at a velocity higher than 190 ft/sec, the data indicate that prematures may be expected at an entry velocity of about 410 ft/sec. No prematures were encountered in 43 tests made at 210 ft/sec, using fuzes that were standard except for heavy fillets in the vane blade corners. Above this entry velocity it is necessary to strengthen the vanes materially to avoid

blade loss and severe bending at water entry, 0.125-in.-thick blades with very heavy corner fillets being required at 410 ft/sec. Seven tests with heavy-bladed vanes at 310 ft/sec and 25 tests at 410 ft/sec yielded no prematures, but it should be noted as mentioned previously that the heavy blades appreciably reduce the arming rate. Prematuring at high entry velocity can be easily controlled by adjusting the number of threads per inch of the arming screw.

Several prematuring trials were made with the high-sensitivity fuzes used in the wooden-deck tests. Seven of the fuzes ranging from 0.31-in. to 0.44-in. steel-block drop test were fired in ASR rounds at an entry velocity of 190 ft/sec, with no resulting prematures; four of the fuzes were also fired at 330 ft/sec without prematuring. Four tests made at 190-ft/sec entry velocity on one Mk 136 defective fuze in which the striker head had been bored out nearly straight inside, omitting the 20° internal cone, gave a reproducible sensitivity of 0.19-in. steel-block drop height and a measured value of 19 g axial sensitivity. The fuze did not premature in any of the four trials.

7.0478. PREMATURE TESTS OF PARTLY PREARMED FUZES WITH NONROTATING LAUNCHER.—A group of Mk 131 fuzes were prearmed 3.0, 4.0, or 5.0 vane revolutions, and the arming screws shortened so the vanes could be reassembled on the shafts in the normal position with cemented axial shear wires in place. The vanes were strengthened with heavy brazed fillets in the blade corners. To eliminate any possibility of test interference, spacer rings of a length dependent on the extent of prearming were assembled below the firing sleeves to prevent excessive setback of the firing assembly during motor acceleration. The rounds were fired at an entry angle of 45°, with retracted setback collar, and caught in a net suspended 30 ft deep.

At 130 ft/sec entry velocity no prematures occurred in seven shots with 4-turn prearmed fuzes, but with 5-turn fuzes five prematures took place in seven shots. At 150 ft/sec velocity, there were no prematures in three shots with the 4-turn fuzes. At 190 ft/sec velocity no prematures occurred in 10 shots with 3-turn prearmed fuzes, but six fuzes prematured in 8 shots of the 4-turn fuzes. At 200 ft/sec all 4-turn fuzes in four shots prematured.

The arming rate data previously obtained enable a determination to be made of the distance of underwater travel required for arming each of these fuze groups. At 130 ft/sec the fuzes which prematured were armed for axial firing after the rounds traveled under water between 5.8 and 6.8 ft, equivalent to depths of between 4.1 and 4.8 ft at the 45° entry angle. At 190 ft/sec the prematures took place after an underwater travel of 9.2 to 9.9 ft, equivalent to depths between 6.5 and 7.0 ft. The fuze axial sensitivity averaged 36 g.

7.0479. PREMATURE TESTS OF FUZES WITH RAPID ARMING RATES IN ROTATING LAUNCHER.—A determination of the minimum arming depth without prematuring for the Mk 156-158 fuze involved complex considerations:

1. All fuzes had to be adjusted to a uniform firing sensitivity equal to the maximum that can be obtained by any combination of fuze tolerances.
2. The arming screws of all fuzes had to be adjusted to the minimum axial

travel to arm a fuze, also determined by the most unfavorable accumulation of tolerances.

3. It was necessary to provide a series of arming rates.

4. The rounds had to enter the water with a rotational speed equal to that measured at the end of normal air flight under service conditions.

5. The rounds had to enter the water at a velocity equal to or slightly higher than the maximum encountered in service use.

6. The rounds should enter the water at an angle and with the yaw that are most conducive to prematuring.

The first consideration necessitated extensive modification of the standard firing assemblies. First, the diameter at the intersection of the two cones within the striker head was adjusted in all assemblies to the 0.405-in. maximum tolerance. Second, the heads of all firing pins were turned to the minimum tolerance of 0.245 in. Third, the forward movement of all striker heads to release the locking balls was equalized at the minimum value of 0.133 in. by means of shims of varying thicknesses between the heads and firing sleeves. Fourth, the weight of the striker heads was maintained between 72.5 and 74.5 gm. Fifth, the firing-spring forces were measured accurately on a commercial spring machine at a compressed length of 0.320 in. The free spring lengths were measured, and the minimum compressed length of each spring at the instant of fuze firing was then adjusted in the individual firing assemblies to give uniformly the specified minimum of 8.5 lb.

The second condition was met by an investigation of fuze tolerance accumulations, which gave 0.207 in. as the minimum arming-screw travel prior to losing contact with the striker head, in a fuze having at the same time the minimum forward movement of the head required to fire. In each assembled fuze, therefore, the radial shear-wire and safety-wire holes were drilled at the same time, after turning the arming screw inward a distance of 0.207 in. beyond the point where the end of the screw first touched the top of the striker head. This setting of course is independent of the means employed to alter the arming rate.

The third item was accomplished in two different ways—(1) by making new plugs and arming screws having multiple threads of rapid leads but retaining the standard 20° blade angle vane assemblies, and (2) by using standard $\frac{1}{16}$ -in. lead plug assemblies with special vanes having increased blade angles and heavily filleted welds. Six groups of 12 fuzes each were assembled, having multiple threads giving leads equivalent to 8, 9, 10, 11, 12, and 13 threads per inch. All threads were dual except the eight, which was triple. Another lot, consisting of five groups of 12 fuzes each, were made up with special vane assemblies having blades set at 25°, 30°, 35°, 40°, and 45°.

The fourth requirement necessitated the design and construction of a motor-driven launcher capable of rotating the entire round at a speed of about 250 rev/min at launching. The rounds were confined within a cage of three long bars, mounted in three heavy steel rings supported by both load and thrust bearings. To the center ring was attached a large gear meshing with a small pinion on an electric motor. The rounds were driven by a grooved lever mounted on one of the bars,

and fitting over one of the tail fins of the round. Igniter connections were brought out through two slip rings and brushes. The launcher pointed downward to give an entry angle of 33° for the tests, and the rounds were retained within it by a small iron wire, looped around the driving member and tail fin, and sheared by rocket motor thrust at firing.

The fifth requirement was met by using motors capable of driving the ASR heads at a velocity of 200 ft/sec. The sixth item could not be introduced into these tests, but probably would not give results materially different from those obtained.

No prematures occurred in 24 tests of the two groups of fuzes which had multiple threads giving leads equivalent to 13 and 12 threads per inch. In 23 tests of the fuzes having a lead equivalent to 11 threads per inch, eight (or 35 per cent) prematures were encountered. In 25 tests of fuzes having a lead equivalent to ten threads per inch, 13 (or 52 per cent) prematures occurred. In 22 tests of the fuzes with leads equivalent to nine and eight threads per inch, all fuzes prematured.

No prematures were encountered in 12 tests of the fuzes having 25° blade angles, but six fuzes in 12 prematured among the 30° vane assemblies. All ten fuzes in ten tests of the 35° blades prematured, as well as both of the two tested having 40° vanes. Additional tests were not made, as it was evident that the 35° vanes were well into the prematuring range.

Both the variable-lead arming screws and the variable-pitch vanes were calibrated for arming-screw revolutions *versus* feet of underwater travel, using the rotary launcher and a steel plate set at known depths under water and at an angle which would bend and lock the arming screws. The calibrations showed that the 12-turn-per-inch screws were arming the fuzes at 10.7 ft of underwater travel, the 11-turn-per-inch screws at 9.4 ft, the 10-turn-per-inch at 8.1 ft, and the 9-turn-per-inch screws at 6.9 ft of underwater travel. Prematures of these high-sensitivity, minimum-arming-travel fuzes in ASR rounds rotated at 250 rev/min at the 200-ft/sec entry velocity and 33° entry angle were thus beginning to occur when arming took place in the region of 9.4 to 10.7 ft of underwater travel, and 100 per cent prematuring was reached when these fuzes were armed at between 6.9 and 8.1 ft of underwater travel. The results with fuzes having the standard 16-turn-per-inch arming screws but different blade angles were in agreement with the above data, as the 25° blade fuzes were arming at 12.1 ft (of underwater travel), the 30° blades at 9.2 ft, and the 35° blades at 7.0 ft. Prematures of the groups of fuzes having vanes of various blade angles therefore were starting between 9.2 to 12.1 ft of underwater travel, and reached 100 per cent prematuring between 7.0 and 9.2 ft of underwater travel. The slightly overlapping data derived from the two methods of increasing the fuze arming rate agree well considering the few tests made—there were 50 per cent prematures among the 30° blade angle fuzes arming at 9.2 ft of underwater travel, and 35 per cent among the 11-turn-per-inch fuzes arming at 9.4 ft. The slightly greater arming depth of the 11-turn-per-inch fuzes compared with that of the 30° blade fuzes should give a marked reduction in prematures, since the deceleration curve of the rounds falls off very steeply at these shallow depths. A distance of 10.7 ft of underwater travel corresponds to a vertical depth of 7.6 ft for a 45° entry angle.

The data indicate that fuzes having a maximum blade angle of 27° or a 12-turn-

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per-inch arming screw should be within the prematuring margin under conditions equivalent to those of the tests, even for fuzes in which the arming screw travels only 0.207 in. before losing contact with the striker head. It should be noted that this travel, possible with present fuze tolerances, is equivalent to only 3.3 turns of the standard arming screw, compared with the usual 4.4 turns found in production fuzes, and leaves the firing pin barely holding the shutter in the *unarmed* position. It is probably for the latter reason that the dimension of 0.470 in. plus 0.000 in. or minus 0.010 in. specified for the distance the arming screw should project beyond the plug base is being disregarded in production, inasmuch as distances of 0.495 in. to 0.537 in. are common. If shallow arming of Mk 156-158 fuzes is desired, it will be necessary, for consistent arming and freedom from prematures, either to curtail tolerances drastically, or to drill the safety-wire and radial shear-wire holes at assembly after the arming screw is rotated a fixed number of turns or travels a fixed distance inward from the point where the screw makes initial contact with the weight. The latter procedure is preferable to tolerance curtailment, and will result in more reproducible fuze performance. It will be necessary also to hold the vane blade angles of all fuzes within close limits.

To decrease the arming depth by increasing the rate of vane revolution, a change in the lead of the arming screw is preferred over an increase in the pitch of the vane blades, in spite of the more difficult manufacturing procedure, for the latter method entails the following objections:

1. The additional blade surface exposed to water impact would result in vane distortion and weakening at water entry velocity less than 200 ft/sec, if the current Mk 156-158 vane strength were retained.
2. Safety against arming on the launcher in heavy seas would be reduced if temperatures were low enough to necessitate retracting the setback collars.
3. The probability of fuzes arming in air flight would be increased if the shear wire were corroded through, omitted in manufacture, or accidentally severed in handling.

7.048. CONCLUSIONS.—The over-all performance of the Mk 156-158 fuze in its present form is relatively satisfactory. However, aside from a thorough check of the design for tolerances and dimensions, there is need for the following changes:

1. An improved means for retaining the setback collar in its forward position in the Mk 156 fuze. A definite spring restoring force instead of friction would be of assistance.
2. A means for keeping the sealing washer in its correct location next to the sealing collar. Production fuzes are often found after shipment to have the washer part way up the threads of the arming screw, where it can interfere with arming and sometimes becomes rolled over, losing its sealing action. It is suggested that if the sealing collar were made slightly longer, with a groove neck topped by a small flange, the washer could be snapped over the flange into the groove. A slight counterbore would be necessary in the fuze plug to accommodate the flange and allow sealing against the washer.
3. The minimum compressed length of the firing spring must be increased. The present spring is compressed to the point where the working stresses are often as high as 160,000 lb/in.², and the spring rate is no longer linear. These factors are

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especially important in gaining uniformity of firing sensitivity, since the final compression of the spring to its shortest length takes place as the fuze fires, with the striker head separating from the firing sleeve. In preparing fuzes for the prematuring tests, it was found necessary to allow 0.320 in. as the minimum compressed length before uniform and reproducible fuze sensitivity could be attained. With a maximum added compression of 0.035 in. during fuze firing, the minimum normal compressed length in the firing assembly should be not less than 0.355 in.

4. A heavier vane assembly is needed to improve fuze sensitivity for deck firing, with blades $\frac{3}{32}$ in. or $\frac{1}{8}$ in. thick.

5. Slight changes are necessary in the striker head dimensions to eliminate any possibility of "half-firing" the fuze. It would be possible in this step to increase fuze sensitivity somewhat, but this may be inadvisable for safety reasons.

6. An increased clearance between the striker head and arming screw should be provided when the fuze is armed. At present, with certain tolerance accumulations, there is only 0.006 in. clearance without allowing for any plus tolerance on the material for the sealing washer, specified as $\frac{3}{32}$ -in. sheet rubber.

7. Probably the most important change is to provide some sort of friction drag acting on the arming screw, preferably only during the first two or three vane revolutions, to eliminate the possibility of arming during air flight in cases where the shear wire is severed or missing. This device should be located if possible within the fuze, where it could be protected against weathering or changes in friction from the lubricating action of water if a rubber ring drag is used; even an external ring in the nose of the fuze plug would be of assistance.

A more comprehensive redesign of the fuze would include a jettisoning vane assembly and a flat fuze face projecting only a short distance in front of the round. This would require a change to a new type of vane assembly and an internal safety mechanism operated by water impact, instead of the present external setback collar. The redesign would result in several major improvements: First, the effective fuze sensitivity would be at least doubled, with firing assured even at 16 ft/sec velocity. Second, prematuring and minimum possible arming depth would remain the same as at present, in spite of the increased effective sensitivity. Third, an armed or partly armed fuze would be no more dangerous to handle than the current design, so far as sensitivity is concerned. Fourth, the fuze would enable higher underwater terminal velocity to be attained in fast-sinking rounds, since the present severe limitation due to vane drag would be eliminated. The improved performance of such a fuze would make the redesign appear desirable.

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