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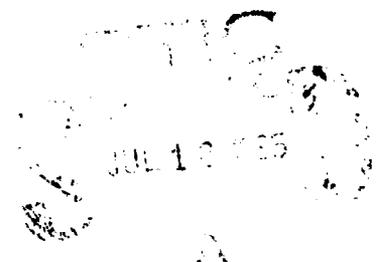
REPORT

MRL-R-955

THE AUSTRALIAN COMPRESSION IGNITION (CI) FUZE: A HISTORY
OF RESEARCH AND DEVELOPMENT AND SUGGESTIONS FOR
USE IN FUZES FOR PRACTICE AMMUNITION

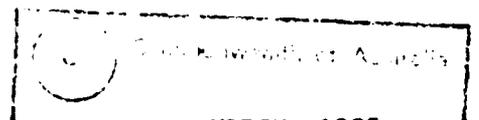
Robert J. Spear

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ABSTRACT

The development of the CI fuze from conception in the mid 1940's through to the final F7 (MRL) and XF8 (EDE) models of the late 1960's is described. Experimental data from this period relevant to recommencing an experimental programme directed towards use of a CI fuze in practice ammunition is detailed. Technical problems of the F7/F2 Fuze have been identified, and research programmes to overcome these have been specified. Some options which would lead to a more cost effective fuze have been presented as concepts.

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TITLE

The Australian Compression Ignition (CI) Fuze: A History of Research and Development and Suggestions for Use in Fuzes for Practice Ammunition

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C O N T E N T S

	<u>Page No.</u>
1. INTRODUCTION	1
2. HISTORY OF RESEARCH AND DEVELOPMENT	2
2.1 <i>Development of the CI Fuze at MRL</i>	3
2.1.1 <i>The Initiator</i>	3
2.1.2 <i>Explosive Fillings</i>	4
2.1.3 <i>Sensitivity and Performance Testing</i>	5
2.1.4 <i>Climatic Testing</i>	6
2.1.5 <i>Fuze Designs Incorporating the CI Initiator</i>	7
2.1.6 <i>Mechanism of Initiation</i>	9
2.2 <i>Development of the CI Fuze at EDE</i>	10
2.3 <i>Factory Production and Service Usage</i>	11
3. SUGGESTIONS FOR PRACTICE FUZES INCORPORATING CI INITIATORS	11
3.1 <i>HE Filled Fuzes</i>	11
3.2 <i>Pyrotechnic Filled Fuzes</i>	12
4. CONCLUSIONS	13
5. ACKNOWLEDGEMENTS	13
6. REFERENCES	14
APPENDIX 1	
APPENDIX 2	

THE AUSTRALIAN COMPRESSION IGNITION (CI) FUZE:
A HISTORY OF RESEARCH AND DEVELOPMENT AND
SUGGESTIONS FOR USE IN FUZES FOR PRACTICE AMMUNITION

1. INTRODUCTION

Energetic materials can be initiated to explosion or detonation by a range of external stimuli. All these initiation processes involve, as a key step in the reaction pathway, degradation of the input energy (electrical, mechanical, shock) into thermal energy concentrated in a small localised region to form a "hot spot". The energetic material in the immediate vicinity of the "hot spot" will ignite if its ignition temperature is exceeded, and may subsequently propagate to explosion or detonation.

The conversion of mechanical energy into thermal energy can occur by three main mechanisms; friction, adiabatic compression and shock [1,2]. Friction appears to be the most common mechanism for initiation of primary explosives, while adiabatic compression and shock (which may involve adiabatic compression) are much more important for initiation of secondary explosives [1,2]. In the case of solid secondary explosives, trapped intercrystalline gas pockets are rapidly compressed, leading to temperature rises of several hundred degrees [1,2].

In the early 1940's a project to develop a detonantless (no primary explosive) in-line impact fuze which relied on compression ignition for functioning was commenced at MRL. The initial models were based on a piston-cylinder system whereby gas in the compression chamber was raised to a sufficiently high temperature to ignite an explosive such as tetryl, RDX or PETN in a flash channel. A number of investigators [3-6] have shown that temperatures sufficient to ignite a range of secondary explosives can readily be achieved using such a system. However, fuzes based on this system were not of sufficient reliability. Work was terminated in the mid 1950's and a new model based on a metal cup-rubber diaphragm was investigated. Results for this system were very promising, although a number of problem areas were identified. This compression ignition (CI) fuze never achieved full service qualification and the project was eventually terminated in the late 1960's.

The need for low cost practice ammunition for the Australian Army has recently been identified as a priority task. A major aspect of such a task is development of a low cost fuze or fuzes compatible with the rounds being developed. One potential solution to this problem is to utilize an in-line CI fuze, which has a number of important advantages over existing out-of-line mechanical fuzes including

1. The fuze contains many fewer parts than a conventional out-of-line safe arming fuze, leading to large cost savings in manufacture and inspection.
2. The fuze contains no primary explosive thus is comparatively safe to manufacture and handle, has longer shelf-life, and does not form sensitive compounds with other parts of the fuze with subsequent danger of premature function in storage and handling.

The aim of the study reported here was to review all the previous work on the CI fuzing systems and to assess specifically their potential for use in practice ammunition. This review was to be carried out with the particular goal of identifying the problems encountered in previous development of the CI fuze, and to devise an experimental programme to overcome these problems such that service qualification could be achieved.

2. HISTORY OF RESEARCH AND DEVELOPMENT

Work on the CI Fuze project finished in the mid to late 1960s, and all of the principal workers involved have subsequently retired. It was necessary therefore to base much of an assessment of achievements and of unresolved problem areas on an exhaustive examination of published and unpublished reports, and file correspondences. This overall picture was supplemented by conversations with the few remaining people who had had involvement with the project.

This section is thus divided into a number of subsections dealing with work done at MRL and EDE, factory production and subsequent service history. Most of the work output came from MRL and this section is consequently the largest. Because neither myself nor any other people who may work on new development of the CI fuze have any previous experience with the concept, the approach taken has been to examine the development in the main text, and to give concise summaries of each report in an Appendix. In this manner it was anticipated that this document would serve as a reference whereby new workers could rapidly familiarise themselves with the CI concept while immediately identifying where relevant information could be found in the published reports. A number of device notations can be found in the Reports, and a Glossary of Terms has therefore been included as Appendix 1.

2.1 Development of the CI Fuze at MRL

Work on the CI fuze at MRL fell into two main design eras. The first period, from the late 1940s to mid 1950s, was concerned with development of designs based on a piston-cylinder compression system. Full details can be found in Refs. [7-15, 17], while related UK work [16, 18, 19] derived from this project is also included. Each of these reports is summarised briefly in Appendix 2. Despite the early promise shown by this system, work was finally terminated because of poor performance as follows:

1. Failure of the cup to slide freely on the spigot (cf piston cylinder) when the angle of impact to normal was increased reduced the effectiveness of the compression system.
2. Effectiveness of compression varied with clearance between cup and spigot, necessitating close tolerances on dimensions of components to achieve uniform performance.
3. The rate of compression of the air in the system decreased as the pressure in the cup increased.

The broad areas covered during this period included fuze design and evaluation of tetryl, PETN and RDX as fillings [7-15], investigation of build-up to detonation in the explosive stemming [13-16] and mechanisms of initiation [17-19].

The termination of work on piston-cylinder designs was followed by design of an initiator based on a cone-shaped air cavity with a plastic or rubber cap held in place by a thin metal cup [20]. The first of these designs, known as (Mould) Type 4, is illustrated in Fig. 1. Development of this concept continued till around 1967, using a combination of static laboratory testing to investigate sensitivity and output of design modifications of the initiator, and field trials to further assess the initiator and assembled fuzes. A number of reports were published during this time and cover areas such as development of the basic design [20-22], development of laboratory tests to assess design models [23-26], experimental studies into design modifications [27, 28], field trials [29-34] and climatic testing [35, 36]. All these reports are summarised concisely in Appendix 2, and all relevant experimental details and results are included.

2.1.1 The Initiator

The Type 4 Initiator (Fig. 1) consisted of a metal body, rubber cap and metal cup. An illustration of the final MRL version, the F2, can be seen in the drawing of the Wandella mortar fuze (Fig. 2) and the Mandurang artillery fuze (Fig. 3).

The initiator body was constructed of brass for all Type 4 series through to the Mark 3, which became known as the Initiator XF1. The Initiator XF2 was identical with the XF1 except that it was made from anodized aluminium.

alloy, and this was the final version, now called Initiator F2, used in the Wandella mortar fuze. The conical air chamber had length 3/16 in and does not appear to have been subjected to experimental variation. The dimensions of the flash holes above the explosive stemming were very critical; the smaller the flash hole, the better the performance [21, 29]. The final selection of length 1/16 in, diameter 0.04 in, was arbitrarily chosen as a compromise between ease of production and sensitivity [21].

A large number of cap materials were initially investigated, eg., see [35], with a neoprene A35 type finally being chosen because of good plasticity at low temperatures. Full details for preparation of a range of neoprene caps, including the DS 300E which was the final choice, have been reported [37]. Both spherical and truncated caps were made [37], but the spherical model was most frequently used and was the choice in the F2 Initiator. Note that the truncated caps gave shorter functioning times than the spherical caps [28]. In the later stages of the CI project, silicone caps (silastic S6508) were investigated and found to improve sensitivity of the initiator to drop weight [29, 32] while giving marginal improvement over the neoprene caps on climatic storage [35]. There have been large advances made in the technology of silicone rubbers over the last 20 years and it seems not unreasonable to expect that quite substantial improvement in fuze performance could be achieved using caps made from modern silicone rubbers.

Cups of steel, brass or aluminium gave little difference in performance and the latter was chosen because of availability; it was part of a commercially produced lipstick holder! The cup was held in place with RD1286 adhesive in the earlier models but enhanced deterioration on climatic storage catalysed by the RD1286 was detected [35]. A cannelluring procedure was subsequently used and this additionally provided a moisture-proof seal for storage. Truncated cups were produced for the truncated caps.

2.1.2 Explosive Fillings

The approach taken throughout was to use a short higher density priming charge which was pressed in first followed by a longer lower density stemming. The priming charge contained a cavity (Fig. 1) which was initially drilled but performance was inferior to one produced by having a small spigot in the flash hole which formed the cavity upon pressing in the explosive. The optimum cavity dimensions were found to be 0.040 in diameter, 7/64 in length; no initiation occurred in the absence of a cavity [21]. Initiation (ignition) occurred in the cavity in the priming filling, burnt down to the stemming and subsequently burnt to detonation in the stemming [27].

CE/PETN (1:1) was initially used as the priming charge, 0.25 g pressed in three increments to density 1.50 g/cm³, with a 1.0 g CE stemming pressed in eight increments to density 1.35 g/cm³ [20, 21]. RDX was subsequently used in all initiators of MRL design. The priming charge was 0.223 g (2 x 1.75 grains), pressed in two increments to density 1.69 g/cm³, with a stemming charge of 1.02 g (9 x 1.75 grains), pressed in nine increments to density 1.43 g/cm³ [25]. A two increment (of 1.75 grain) RDX priming charge gave the best initiator output, with one and four increments being definitely inferior, and three marginally so [24]. Buildup to detonation in

the stemming occurred after 0.8 - 1.0 in of the total 1.7 in length, with an average detonation velocity of 7600 m/s being achieved [27]. Sieved grade 1A RDX (52-200 mesh) was used in most cases, although in one trial British Grade 1 recrystallized RDX was employed and resulted in a sensitivity increase [29]. Interestingly, RDX-polyethylene was reported to give substantial increase in sensitivity to drop weight in F2 initiators when used in the priming charge; 50% initiation conditions were 2 lb/3.5 ft cf 2 lb/8.6 ft for Grade 1A filled initiators [38]. However use of RDX-polyethylene in the stemming resulted in failure to achieve detonation [38].

Some F2 initiators were filled with PETN as the two priming increments followed by an RDX stemming and found to have increased sensitivity to drop weight relative to the normal F2 initiators [31].

2.1.3 Sensitivity and Performance Testing

Sensitivity and output parameters of the initiators were determined by laboratory testing. The initiator was held rigidly and impacted by a falling weight [23, 24] with output being assessed by indentation in an aluminium witness block [25]. Sensitivity was determined using the Bruceton staircase method, and a typical F2 initiator impacted by a 2 lb weight had height for 50% initiation of 8.6 ft, $\sigma = 0.1$ ft. Output was considered acceptable if the indentation into an aluminium alloy witness block was in the range 0.098-0.114 in [25].

A card gap test was developed to quantify fuze sensitivity [29]. Filled rounds were fired horizontally at a target of 9 oz jump cards (thickness 0.145 in) held in a support frame. Thickness of the target was varied by the number of cards, and fuze sensitivity was determined using the Bruceton staircase method. The target thickness for 50% functioning of normal F7 super quick (SQ) fuzes was 20 ± 2 cards when fired at charge 1 (approx. 300 ft/s) [29, 30]. Additional field tests covered all types of target e.g. meadow, snow, water, rocky ground [38], with observation of impact and recovery of fuzes.

A major problem encountered was that initiators which displayed marked sensitivity differences in drop weight testing, either by design or after climatic cycling [35], showed little difference when fitted into fuzes and field tested [29-32]. It was felt that this difference arose because the field test (against soil) resulted in a significantly longer duration of impact force than the drop weight test [26]. Accordingly an investigation was undertaken to modify the laboratory test method such that results for drop weight tallied with field tests. A drop weight test consisting of a primary and secondary plunger was developed and gave consistent results [26]. A field test was planned to confirm the results but this does not appear to have been carried out.

2.1.4 Climatic Testing

Initiators and fuzes of various types were subjected to ISAT(A) and in some cases ISAT(B) storage. Breakdown, visual assessment and laboratory and field testing of sensitivity was then carried out.

Loss of sensitivity to drop weight initiation upon ISAT(A) storage was recognised as a problem in the early stages of development. For example, Mandurang XF5 fuzes had decreased significantly in drop weight sensitivity after 6 months, while XF1 Initiators exhibited a marked decrease in sensitivity after 6 months (2 lb/15-27 ft for 50% initiation) and after 12 months was near the limit of the drop tower (2 lb/35 ft cf 2 lb/8.6 ft for 50% initiation of normal XF1 initiators) [35]. A series of trials was undertaken to determine the cause of this loss of sensitivity [35].

The cup was originally sealed onto the initiator body with RD1286 cement, and initiators sealed in this manner lost sensitivity more rapidly than cannellured cups. Use of sealant was therefore discontinued. Deterioration of the caps was not the cause; caps stored separately under ISAT(A) conditions functioned normally when reassembled into initiator bodies. RDX (Grade 1A as then normally used) stored under ISAT(A) conditions also functioned normally when pressed into initiator bodies. It should be noted that initiators filled with Grade 1A RDX or RDX precipitated from acetone as the priming charge deteriorated significantly faster than an experimental batch filled with British Grade 1 recrystallised RDX; however the latter was a sample 20 years old and the significance of the result is uncertain.

It was found that if the cup and cap was removed from the initiator body for visual inspection then refitted, some of the lost sensitivity to drop weight was restored, but the extent of recovery decreased with increasing time. There thus appeared to be two deterioration mechanisms: a short term reversible and a longer term irreversible.

Removal and refitting only replaces the atmosphere in the compression chamber. No contaminants were detected (by glc) in the air in the compression chamber after 6 months ISAT(A) storage, but the oxygen to nitrogen ratio was very low. The short term reversible loss of sensitivity is not likely to be caused by decrease of pressure in the cavity by scavenging of oxygen since $T \propto P_{\text{final}}/P_{\text{initial}}$ and not on their absolute magnitudes; initiation can still occur by drop weight at pressures as low as 10^{-5} mm [1]. A more likely explanation can be proposed on the basis of results from Yuill and Evans [4], who found that higher temperatures must be achieved to ignite explosives in a compression apparatus when air is replaced by nitrogen. For example, the minimum temperatures for incipient ignition of PETN in a compression apparatus were found to be 1000°C (oxygen atmosphere), 1500°C (air), >1600°C (nitrogen) and >5000°C (argon). Results for nitroglycerine follow a similar pattern but the temperatures required for ignition are lower [4]. Preliminary testing showed that oxygen was removed from a sealed air system by both neoprene and silicone plugs at 140°F, with the silicone plugs removing oxygen less quickly.

The reasons for the longer term loss of sensitivity were not determined although it was concluded that the likely cause was decreased thermal sensitivity of the RDX in the cavity. Possible mechanisms which were suggested included action by the occluded acid in the RDX and coating by the plasticiser from the rubber cap. However the study was a limited exploratory one and could be improved greatly by the use of modern instrumentation. For example, it was not possible to accurately determine whether the volume of the cavity had decreased, while the methods used would probably not have detected surface contamination of the RDX.

As might be expected, loss of sensitivity occurs even more rapidly under ISAT(B) storage; F2 Initiators exhibited pronounced loss of sensitivity after only 2 weeks storage [26, 32]. However it must be emphasised that there is little evidence to suggest that long term ambient storage leads to loss of initiator sensitivity. The investigation by AQAU of Fuzes PD F7 which had been held in three separate depots for up to 5 years revealed a very marginal sensitivity increase (2 lb/8.15 ft for 50% initiation) [36]. Although it was claimed that they failed the functioning test, the indentations produced in the witness block (average 0.096 in) were only slightly under specification and could have resulted from use of slightly harder witness blocks (cf Ref [25]). Perhaps output had dropped, but it was a small drop and seems unlikely to have been the cause of the service malfunction at that time [36].

2.1.5 Fuze Designs Incorporating the CI Initiator

Modified Army ammunition fitted with the CI initiator were 3 in, 4.2 in and 81 mm mortar, 25 lb, 5.5 in and 3.7 in artillery, and 105 mm Howitzer [22, 39]. Although all these concepts were subjected to field trials, the main emphasis was on 3 in (Fuze PD SQ XF2) and 81 mm (Fuze PD SQ XF7, "Wandella", later abbreviated to Fuze F7) mortar rounds. Most of the following discussion will accordingly refer to the Wandella fuze since most results are available for this system. Other projected Army applications are described in Ref. [39]. Designs for RAAF ordnance incorporating the CI initiator included 25 lb practice and service bombs, a 1000 lb HE aircraft bomb and 40 mm ammunition [22, 39] but development did not progress to such an advanced stage as the Army items.

Wandella Mortar Fuze

This fuze, which could be fitted either to 3 in or 81 mm mortar rounds, is shown in Fig. 2. The fuze functioned by one of two different mechanisms:

1. Against hard, resistant targets, the nose and body of the fuze collapsed, causing the diaphragm (the base of the nose) to impact on the cup.
2. On plastic or fluid targets the target material entered the nose, causing the diaphragm to separate at the weakened section and impact the cup.

Much of the early testing was on Fuze XF2 but with the adoption by Army of 81 mm mortar ammunition this was superseded by Fuze XF7 (F7). However the results are applicable to either.

It is a fair assessment that these fuzes suffered from an unacceptably high rate of "blinds" on certain target types. Initially this included quite a range of targets [21, 22] but in the final designs had been narrowed down to rocky ground, although performance at low charges (eg. 1 or 0) was much inferior to the service Fuze No. 162. It is also fair to say that this poor performance was almost certainly associated with nose design [32]. Relative performance data for Fuze XF2 and Fuze No. 162 are listed in ref. [39] for a variety of target types. It should be remembered that Fuze No. 162 is based on a primary explosive initiation system and is significantly more sensitive than Fuze XF2 with only a secondary explosive filling.

The nose section (Fig. 2) consisted of a threaded unit which screwed into the body and a diaphragm made of a light alloy disc held in by shear pins. These shear pins initially had a 270 lb push out loading and performed satisfactorily [21]. This loading was increased to 2000 lb to ensure non-functioning against foliage and light targets [21] but was later reduced to 1000 lb to improve performance; safety did not appear to be compromised [22]. The plastic insert was included to improve functioning on soft targets [39]. It should be noted that one suggestion made to explain the poor correlation between static laboratory drop weight tests and field tests, as discussed in Section 2.1.2, was that the latter were only measuring the ability of the diaphragm to shear and once this occurred the initiator always functioned [29-32]. There seems little doubt that performance could be improved by new nose designs.

The fuzes passed acceptance trials and the F7 was ultimately used by the Army in the role of a practice fuze for 81 mm mortar. Its use was phased out by 1975.

Two trials were conducted on modified fuzes for 81 mm mortar incorporating a delay [33, 34]. Although successful to the extent that the feasibility of the concept was proved, further development was not undertaken.

Mandurang Artillery Fuze (XF5)

The unit is shown in Fig. 3 and some results for field trials can be found in Ref. [33]. Performance seemed to be comparable with the Wandella Fuze when the latter was fired at higher impact velocities. The higher set-back force of artillery rounds presumably decreased the safety margin and the design possibly was not pursued for this reason. However extensive safety trials were carried out [39] using the XF5 in 25 lb, 5.5 in and 3.7 in artillery rounds and complete freedom from prematures was established. Some of the acceptance trials were also undertaken and all passed.

2.1.6 Mechanism of Initiation

The initial concept of a CI fuze was based on the assumption that adiabatic compression of the air in the chamber led to a temperature in excess of the ignition temperature of the explosive in the flash channel. All evidence relating to initiation by drop weight is consistent with this mechanism [27-31].

The temperature T_2 reached during compression is given by

$$T_2 = T_1 \left(\frac{V_1}{V_2} \right)^{\gamma-1} \quad \text{where} \quad \begin{array}{l} T_1 = \text{initial temperatures} \\ V_1 = \text{initial volume} \\ V_2 = \text{final volume} \\ \gamma = \text{ratio of specific heats} \end{array}$$

Accordingly, venting the chamber by drilling 0.04 in holes into the flash channel [28], replacement of air ($\gamma = 1.4$) by propane ($\gamma = 1.1$) [29] and evacuating the compression chamber [30, 31] dramatically decreases drop weight sensitivity. The latter observation probably results more from diminished heat flux since $T_2 \propto P_2/P_1$ and not their absolute magnitudes. That the rate of compression is very important can be seen from the observation that the functioning time $\propto 1/\text{impact velocity}$ for drop weight initiation, and the chamber must be compressed at least 0.20 in in less than 5 ms for functioning [28]. The major part of the functioning time is taken up by collapse of the cap and cup; radiographic evidence is consistent with this picture [28].

However, as mentioned in Section 2.1.5, modifications which diminish sensitivity to drop weight did not necessarily lead to decrease in sensitivity to impact in field trials, and usually did not. Howlett [28] considered four mechanisms for initiation:

- a. adiabatic compression of air under the cap.
- b. initiation by shock waves generated in the air by the high speed jet of rubber from the cap.
- c. ignition by heat from friction of the rubber as it rubs down the cone and flash hole.
- d. stab initiation; the rubber jet moving down the flash hole should be quite rigid.

He concluded that at slow compression rates mechanism a. operates, while both a. and b. operate at higher compression rates. Extrapolating to field tests where compression rates will be further increased means that mechanism b. should become increasingly important and perhaps dominant. Certainly there appears to be little correlation between results for field testing and drop weight testing but whether this is due to a change in initiation mechanism (a. to b.), or to the longer duration of impact under field conditions [26], or to field testing merely measuring the ability to shear the nose diaphragm, with all initiators functioning once this has occurred, is not known.

The mechanism of collapse of the nose/diaphragm was discussed in the previous Section 2.1.5.

2.2 Development of the CI Fuze at EDE

The principal role of EDE (at that time ADE, Army Design Establishment) in development of the CI fuze had been in assisting MRL. The only person still at EDE who had been active in this program was Mr A. Scolaro. Comments in this section are based on discussions with Mr Scolaro, Mr K. Rowles (Engineer-in-Charge, Ammunition Group) and Mr G. Letcher (Head, Fuzes and Initiator Section). No reports were published from EDE on this project.

The major task undertaken by EDE was to improve the sensitivity of Fuze F7, and this led to Fuze XF8. XF8 differed from F7 in a number of ways.

1. The initiator, instead of being a single unit as in F2 was split into a short initiator (EDI 3) with a following gaine (EDG 6 or 7).
2. The initiator was fitted with truncated caps and rubbers rather than the hemispherical design of Initiator F2.
3. PETN was substituted for RDX.
4. The nose frontal area was reduced to conform with (then) service specification.

Some experimental results from field trials are reported in Refs. [30-32].

The results were in general disappointing. Function of the fuze on rocky ground and at high angles of impact to normal was still poor with an unacceptably high rate of "blinds". There seems to be no doubt that the nose design was unsatisfactory [32] and this contributed to the problem, while the length of stemming in Gaine EDG7 appeared to be marginal [32]. It has been noted previously [31] that Initiator EDI3 had significantly larger indentation power, under drop weight testing, for an equivalent weight of RDX in a shorter stemming than Initiator F2; this was possibly due to the tapered stemming design of EDI3 which resulted in favourable density increments.

A secondary task of incorporating a safe arming mechanism between the initiator and gaine was not pursued following the failure of the major XF8 project. Work was finally phased out in the late 1960s when it was concluded that the sensitivity could not be made sufficiently high to meet Army requirements.

In an attempt to summarise just what went wrong, it was stated: "additional operational requirements placed on the fuze such as post impact delay led ultimately to attempts to force the CI principle into applications for which it was unsuited, ie its unique advantage was lost."

2.3 Factory Production and Service Usage

The Fuze F7 (Wandella) was accepted for use in the Australian Army as a Limited Standard Fuze for 81 mm Mortar Cartridges. As such it was used in training ammunition for 81 mm mortar from the late 1960's to mid 1970's when its use was discontinued. All production was at EFM and production records were found for the period 1966-1971, covering Lot Nos. 8-50; the fuzes retested in 1975 [36] were from Lot 50. A total of 157,000 units were produced during this time, with presumably a few more having been produced as Lots 1-7 for which records were not available.

The reason given for Army discontinuing use of Fuze F7 was that it produced excessive "blinds" during service use [40]. Whether this was due to target characteristics, eg, performance seemed to be particularly poor on rocky ground, or lack of sensitivity in the explosive train, is a matter of conjecture. It has also been suggested that the rate of malfunction appeared to increase with time [36], but there appears to be no "hard" data to support this. The lack of safe-arming, which became much more important in the late 1960's, does not appear to have been a factor in discontinuing service use, but again opinions differ.

The initiator was also introduced into service with the RAAF, its use being to detonate the HE charge of destroy devices in remotely controlled target aircraft; the initiator was functioned hydraulically [39]. No attempt was made to determine the subsequent service history of these initiators, or to find other minor roles for which the F2 may have been used.

3. SUGGESTIONS FOR PRACTICE FUZES INCORPORATING CI INITIATORS

The CI concept has a number of features which appear attractive for use in a fuze for practice ammunition. The major advantage should be cost savings over a conventional safe-arming fuze due to the much lower number of component parts. One could additionally envisage the fuze parts being moulded from plastic composite materials which should lead to further substantial cost savings. If this was to be pursued as an option it would be necessary to show that the fuze performance had not deteriorated, such as that the confinement was sufficient for detonation of the stemming to take place.

Two types of fuze based on the CI principle seem feasible, namely an HE filled, and a pyrotechnic filled. Options for both these concepts are discussed below.

3.1 HE Filled Fuzes

Virtually all previous work on CI Fuzes has been on designs filled only with HE. The Fuze F7 which was previously in Army use as a practice fuze was HE filled and fitted to an HE round. However, as discussed in Ref. [40],

design improvements would need to be made, and demonstrated, before Army would consider reintroduction of a Fuze of the F7 type.

Two problem areas where performance improvement could be achieved have been identified in this report.

(i) Nose Design

This appeared to be a problem right through development and is probably the principal reason for the high incidence of "blinds" on certain target types. Part of this problem probably arose from Army requirements for non-functioning on foliage and safety requirements regarding muzzle and in-bore prematures and collision with (say) a hand near the muzzle. Performance requirements can be reduced for practice ammunition, while the decreased payload permits some relaxation in fuze safety criteria. New nose designs should be investigated, in particular with lower shear thresholds consistent with maximum sensitivity while meeting safety requirements. Army must define what target types and conditions are required for functioning, and if possible a "worst-case" target. Safety requirements must also be defined given that there is no safety and arming mechanism, or alternatively a simple safe-arming mechanism should be developed.

(ii) Desensitization Resulting from Climatic Storage

As discussed in Section 2.1.4, there appear to be two mechanisms leading to loss of impact sensitivity of CI Initiators after ISAT storage. An experimental programme at MRL aimed at countering these effects has commenced. The short term loss of sensitivity due to depletion of oxygen from the compression chamber by reaction with the neoprene or silicone rubbers should be overcome by the use of modern silicone rubbers which absorb virtually no oxygen even at elevated temperatures. The cause of the longer term desensitization must be identified. If it is due either to the RDX used then (Grade 1A) or to plasticiser migration from the cap to the cavity, this problem should be overcome using the improved materials now available.

The use of fillings such as PETN and HMX as the priming increment may also have advantages in overcoming the problem of desensitization, but the sensitivity of these fillings must be matched to safety requirements. PETN could also have advantages in a plastic moulded fuze since less confinement than RDX is needed for the transition from deflagration to detonation to occur.

3.2 Pyrotechnic Filled Fuzes

Towards the end of the CI fuze project some experimental XF8 fuzes were prepared with an EDI 11 initiator filled with barium styphnate or a boron-lead oxide composition [41]. The initiator was shuttered from the HE filled gaine, the aim being to improve the unsatisfactorily low sensitivity of XF8. Performance of F2 Initiators filled with SR61 (B, 10%; Bi₂O₃, 85%;

Cr₂O₃, 5%) and SR87 (B, 10%; Bi₂O₃, 53%; Cr₂O₃, 37%) were also investigated, but the results appear to have been disappointing [42].

In the projected application to a practice ammunition fuze, it may not necessarily be required that the fuze filling detonate, and a pyrotechnic fill to ignite a spotting charge may be satisfactory. Before development of such a concept could proceed, a precise definition of what output is required from the fuze would be necessary.

4. CONCLUSIONS

None of the people who had a major involvement in development of the CI fuze at MRL are still at MRL, with the exception of Mr W. Connick, now Director. This report was written to overcome this deficiency, and was intended to serve as a background document to bridge the intervening two decades between termination of work on Fuze F7 and reinvestigation of the CI fuze concept for practice ammunition which is now commencing. The evolution of the CI fuze is described and all experimental work relevant to devising new experimental programmes are covered. Technical problems of the previous F7/F2 Fuze have been identified and research programmes to overcome these problems have been specified. Some options which would lead to a more cost effective fuze have been presented as concepts.

The development of fuzes for practice ammunition based on the CI concept seems feasible both on technical and economic grounds. Fuze F7 was used previously in this role, but service performance was unsatisfactory. Substantially increased performance would have to be proved before Army would reintroduce it into service. It cannot be stressed too strongly, however, that before development proceeds to an advanced stage Army must define safety and performance requirements for the projected ammunition. Although Ref. [40] does define some criteria, further definition of requirements would be desirable. Ref [43] could be used as a basis for deciding safety and suitability for service.

5. ACKNOWLEDGEMENTS

Firstly I must thank Mr Lance D. Redman for doing much of the detective work in finding equipment, material and drawings still extant from the CI project, and sorting through mountains of such bits and pieces. Secondly, I give sincere thanks to those I pestered unmercifully in my attempts to drag up the past and get to the bottom of the CI Fuze story. These include Mr A. Scolaro, Mr K. Rowles and Mr G. Letcher of EDE, Mr A.J. Bridger of EFM, Mr G.D. Thomson and Mr I. Glanville of FDL, and Mr W. Connick, Dr P. Dunn and Mr M.G. Wolfson of MRL. I also gratefully acknowledge the help give by Mr J.R. Bentley and Mr T.E. Symes with regard to discussions on future technical options for the CI Fuze.

6. REFERENCES

1. Bowden, F.P. and Yoffe, A.D. (1952). "Initiation and Growth of Explosion in Liquids and Solids," Cambridge University Press, UK. Chapters III and IV.
2. Bowden, F.P. and Yoffe, A.D. (1958). "Fast Reactions in Solids", Butterworths Scientific Publications, London, UK. Chapter V.
3. Bowden, F.P., and Gurton, O.A. (1949). Proc. Roy. Soc. (London), A198, 350.
4. Evans, J.I., and Yuill, A.M. (1958). Proc. Roy. Soc. (London), A246, 176.
5. Johansson, C.H., and Selberg, H.L. (1956). Appl. Sci. Res., A5, 439.
6. Bryan, G.J. and Noonan, E.C. (1958). Proc. Roy. Soc. (London), A246, 167.
7. Anon (1952). "Study of New Principle of Fuze Design: Compression Initiation Fuze. Progress Report No. 1", Defence Research Labs, Maribyrnong [Secret].
8. Anon (1953). "Study of New Principle of Fuze Design: Compression Initiation Fuze. Progress Report No. 2", Defence Standards Labs, Maribyrnong [Secret].
9. Anon (1953). "Study of New Principle of Fuze Design: Compression Initiation Fuze (Detonantless Fuze). Progress Report No. 3", Defence Standards Labs, Maribyrnong [Secret].
10. Anon (1954). "Study of New Principle of Fuze Design: Compression Initiation Fuze (Detonantless Fuze). Progress Report No. 4", Defence Standards Labs, Maribyrnong [Secret].
11. Anon (1954). "Study of New Principle of Fuze Design: Compression Initiation Fuze (Detonantless Fuze). Progress Report No. 5", Defence Standards Labs, Maribyrnong [Secret].
12. Anon (1955). "Study of New Principle of Fuze Design: Compression Initiation Fuze (Detonantless Fuze). Progress Report No. 6", Defence Standards Labs, Maribyrnong [Secret].
13. Osborne, W.P., Seddon, K.C. and Sinclair, O.J. (1948). "The Compression Initiation Principle for Fuzes. A Study of the Problems Associated with its Application to Fuze Design. Progress Report No. 3", Defence Research Labs, Maribyrnong [Confidential].
14. Osborne, W.P., Seddon, K.C. and Sinclair, O.J. (1949). "The Compression Initiation Principle for Fuzes. A Study of the Problems Associated with its Application to Fuze Design. Progress Report No. 5", Defence Research Labs, Maribyrnong [Classification unknown].

15. Anon (1954). "Fuze Development - Detonantless System. The Development of an Initiation System Filled CE (Tetryl). Report on Exploratory and Developmental Work During Period 1947-1952", Defence Standards Labs, Maribyrnong.
16. Peton, S.V. (1961). "A Modified R.D. Gaine System for Initiating Detonation", ARDE Memorandum (MX) 41/61, Armament Research and Development Establishment, Fort Halstead, Kent, UK [Confidential].
17. Seddon, K.C. (1959). "Australian Experimental Detonantless Fuze 20 mm MSL, Type 3, Mod. 1, Report on Development, Performance and Mechanisms of Functioning", DSL-R-234, Defence Standards Labs, Maribyrnong.
18. Hills, H.F. (1950). "An Investigation into the Mode of Functioning of the Australian 20 mm Fuze MSL3 Mod. 1", Report No. 4/50, Armament Research Estab., Fort Halstead, Kent, UK [Secret].
19. Hutton, E.A. (1951). "An Investigation into the Mode of Functioning of the Australian 20 mm Fuze MSL3 Mod. 1. Parts II-IV", Report No. 4/50, Armament Research Estab, Fort Halstead, Kent, UK [Secret].
20. Anon (1958). "Fuze Development - Detonantless System. The Development of an Initiation System Filled High Explosive", DSL-R 236, Defence Standards Labs, Maribyrnong, and earlier report cited therein.
21. Osborne, W.P. (1958). "Development of Fuze, DSL Type 4 Mark 3", DSL-R-238, Defence Standards Labs, Maribyrnong.
22. Osborne, W.P. (1961). "Fuze Development - Detonantless System. Application to Service Fuzes. Progress Report July 1958 - November 1960", DSL-R-246, Defence Standards Labs, Maribyrnong.
23. Connick, W., Wiese, E.F. and Jackson, J.G. (1965). "A Sensitivity Test for Static Functioning of Compression Ignition Fuze Initiators", DSL-TM-11, Defence Standards Labs, Maribyrnong.
24. Connick, W. and Wolfson, M.G. (1965). "An Investigation of the Donor Power of Compression Ignition Fuze Initiators. Part I", DSL-TM-13, Defence Standards Labs, Maribyrnong.
25. Wiese, E.F., Jackson, J.G. and Wolfson, M.G. (1966). "An Investigation of the Donor Power of Compression Ignition Fuze Initiators. Part II", DSL-TM-15, Defence Standards Labs, Maribyrnong.
26. Humphris, P.J. and Wiese, E.F. (1967). "A Drop Weight Sensitivity Test for Compression Ignition Fuze Initiators. The Development of a Laboratory Test to Facilitate Prediction of Initiator performance in the Field - Part I", Explosives and Ammunition Composite Note No. 1/67, Defence Standards Labs, Maribyrnong [Confidential].

27. Howlett, S.L. (1963). "A Study of the Initiation and Growth to Detonation in an Explosive Stemming", DSL-R-265, Defence Standards Labs, Maribyrnong.
28. Howlett, S.L. (1967). "Laboratory Tests on the DSL Compression Ignition Detonator", DSL-TM-21, Defence Standards Labs, Maribyrnong.
29. Connick, W., Wiese, E.F. and Greenham, J.A. (1965). "The Variable Card Target Sensitivity Test for Compression Ignition Fuzes. Part I", Explosives and Ammunition Group Note No. 2/65, Defence Standards Labs, Maribyrnong [Confidential].
30. Wiese, E.F. and Greenham, J.G. (1966). "Report on Trial ED 66/1. A Trial of Compression Ignition Fuzes", Explosives and Ammunition Composite Note No. 5/66, Defence Standards Labs, Maribyrnong [Confidential].
31. Wiese, E.F. and Thomson, G.D. (1966). "Report on Trial ED 66/2. A Trial of Compression Ignition Fuzes", Explosives and Ammunition Note No. 11/66, Defence Standards Labs, Maribyrnong [Confidential].
32. Humphris, P.J., Wiese, E.F. and Thomson, G.D. (1966). "Report on Trial ED 66/3. A Trial of Compression Ignition Fuzes", Explosives and Ammunition Note No. 12/66, Defence Standards Labs, Maribyrnong [Confidential].
33. Wiese, E.F., Bullock, N.C. and Greenham, J.A. (1964). "A Preliminary Report on the Aims and Results of Trials in the Development of a Detonantless Delay Fuze", Explosives and Ammunition Group Note No. 3/64, Defence Standards Labs, Maribyrnong [Confidential].
34. Wiese, E.F., Pinson, D.J. and Greenham, J.A. (1965). "A Report on the Aims and Results of a Further Trial of the Detonantless Delay Fuze", Explosives and Ammunition Group Note No. 7/65, Defence Standards Labs, Maribyrnong [Confidential].
35. Wiese, E.F. and Jackson, J.G. (1966). "An Investigation into the Effect of Climatic Storage on the Drop Weight Sensitivity of Compression Ignition Fuze Initiators", Explosives and Ammunition Group Note No. 3/66, Defence Standards Labs, Maribyrnong [Confidential].
36. Pierce, J.R. (1976). "Investigation No. 1390-3M-QAD3. Fuze PD F7 Malfunctions in Service. 3AQAU Final Report".
37. Dunn, P. and Liggins, T. (1967). "Rubber Plugs for Detonantless Fuzes", DSL-TN-97, Defence Standards Labs, Maribyrnong.
38. Humphris, P.J. and Dillon, T. (1965). "Polyethylene Wax - A New Desensitizer for RDX/TNT. Part 1. Coating RDX Grade 1A with 1% Polyethylene Wax AC629," Explosives and Ammunition Group Note No. 11/65, Materials Research Labs, Maribyrnong [Restricted].

39. Anon (1963). "Application of the Detonantless System to Service Fuzes", ABCA Ad Hoc Working Group on Priority Standardization Effort. Australian Proposal for PSL Item 36 [Secret].
40. Smith, M.M. and Dace, R.J. (1984). "Fuzing Options for Current 81 mm HE and Smoke WP Mortar Ammunition", Materiel Branch/Munitions Division Report, Dept. of Defence, Canberra.
41. Humphris, P.J. and Wiese, E.F. (Approx. 1966). Unpublished notes.
42. Greenham, J.A. (Approx. 1965). Unpublished notes.
43. Australian Ordnance Council (1985). "Design Safety Principles for In-line Mechanical Initiation Systems for Small Calibre Ammunition", AOC Proceeding No. 119.85.

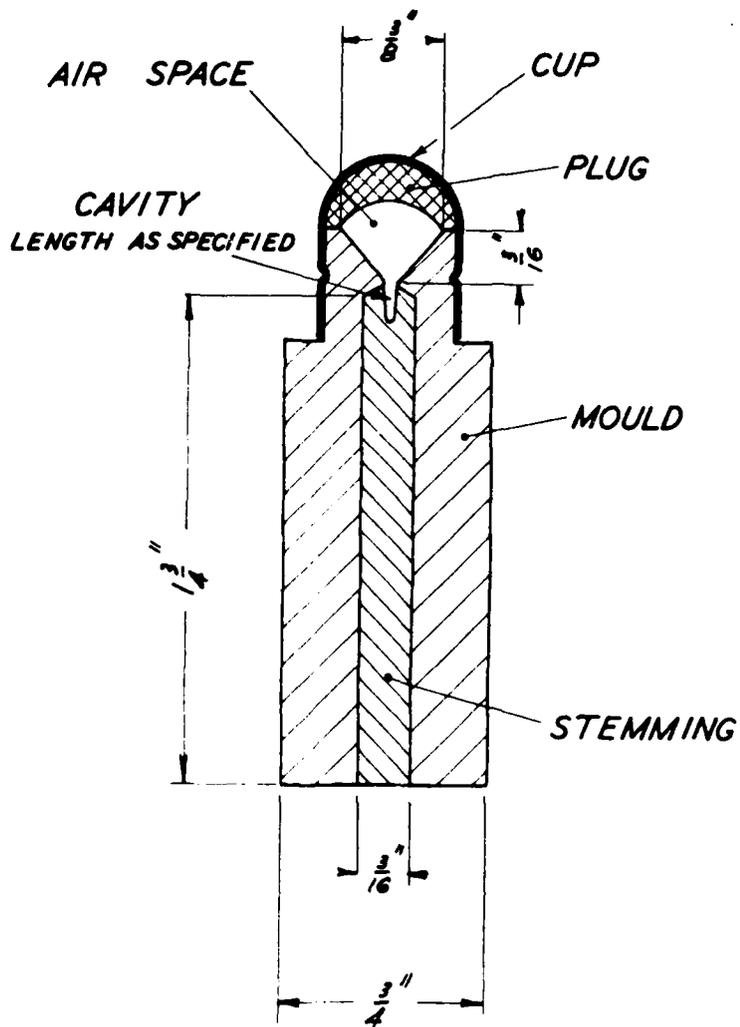


FIGURE 1. An illustration of the first of the CI initiators based on the compression chamber/rubber cap/metal cup design, taken from Ref [20]. The rubber cap is called a plug in the above diagram.

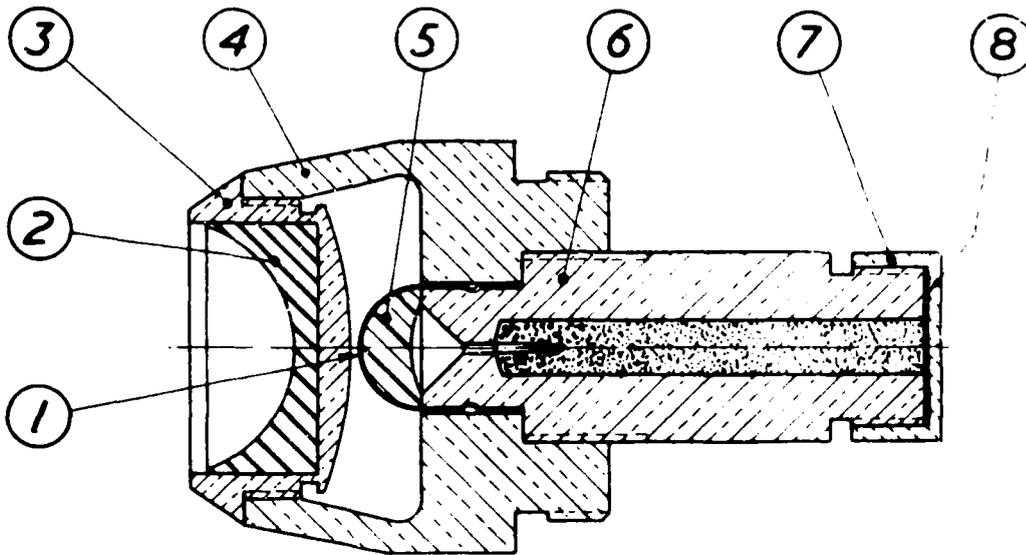


FIGURE 2. An illustration of the Wandella F7 Fuze for 81 mm Mortar ammunition. The Fuze body and magazine are not shown. The numbers on the diagram refer to the following components.

1. Metal cup
2. Insert
3. Nose shear diaphragm
4. Nose body
5. Rubber cap
6. Initiator body (mould)
7. Stemming cover
8. Paper disc

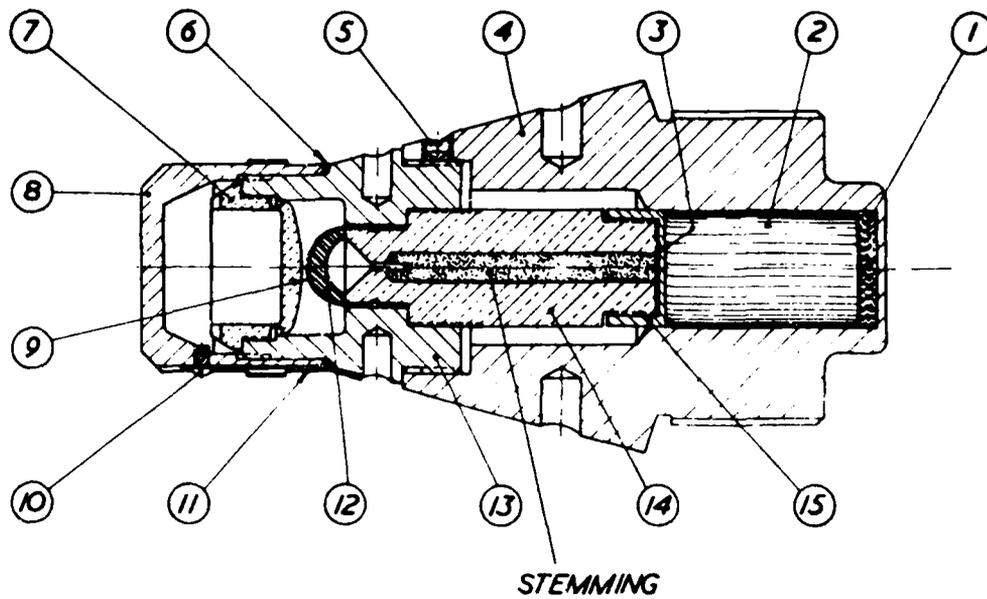


FIGURE 3. An illustration of Fuze XF5 (Mandurang) for Field Artillery. The numbers refer to the following components:

1. Felt pad
2. Tetryl pellet
3. Paper disc
4. Adaptor
5. Set Screw
6. Washer
7. Nose shear diaphragm
8. Transit cap
9. Metal cup
10. Drive screw
11. Cap spring
12. Rubber cap
13. Body
14. Initiator (mould)
15. Stemming cover

APPENDIX 1

GLOSSARY OF TERMS APPLICABLE TO THE CI FUZE

The following abbreviations can be found in the reports on the CI fuze. Because of the nature of the development of the fuze, several devices were known successively by different notations, but this is not always apparent without careful scrutiny of the entire collection of reports. A complete listing of the X series fuzes can be found in Ref. [39].

Fuze: The entire assembled item including nose and magazine.

Initiator: The compression ignition system containing the compression chamber and explosive stemming.

Gaine: In later EDE designed models the original initiator was split into a shorter initiator and a second element termed the gaine. The initiator and gaine were separated either by a safety and arming shutter or a delay element.

Fuze Types:

Types 1-3 (MSL1-3): Early designs based on a piston/cylinder mechanism for compression. Superseded. See Refs. [7-15, 17-20].

Type 4: The first of the designs based on a compression chamber consisting of a cone-shaped air cavity, rubber cap and metal cup. See Refs. [20, 21]. The initiator is shown in Fig. 1.

XF2, formerly Type 4, Mark 3: A fuze for 3 in mortar ammunition, contained the XF1 initiator. See Ref. [22].

XF3: Very similar to the XF2, developed for 4.2 in mortar ammunition. See Ref. [35].

F7 (Wandella). Formerly XF7: A fuze developed specifically for 81 mm mortar ammunition. The Wandella contained the F2 initiator. See Refs. [29, 30-32, 36] and Fig. 2.

XF5 (Mandurang): A fuze very similar to Wandella, but with a redesigned nose for field artillery. See Refs. [22, 33-35] and Fig. 3.

EDF7: An early model of the XF8 made up of the F7 nose, initiator EDI 11 and Gaine EDG 6. See Ref. [32].

XF8: The final version of the EDE CI system based on an initiator/gaine assembly. See Ref. [32].

Initiator Types:

XF1: Initiator used in the Type 4, Mandurang and early F7 fuzes, machined from brass. See Refs. [23, 24, 27, 33-35].

F2, formerly XF2: Differs from the XF1 in being made from anodized aluminium. The Wandella used an F2 Initiator. See Refs. [23-25, 30] and Figs. 2 and 3.

EDI 1,2,3 and 11: Short initiators developed by EDE, differing slightly from each other. All employed a truncated cap and cup rather than the hemispherical type used in the XF1 and F2, and were used in conjunction with one of the gains listed below. See Ref. [31, 32].

Gain Types:

EDG 6,7: Gains used with Initiators EDI 1,2,3 and 11, separated by a shutter or delay element. See Ref. [31, 32].

APPENDIX 2

SUMMARY OF PUBLISHED WORK ON THE CI FUZE

A summary of each Reference published by MRL or related to the MRL CI fuze concept. References [7-19] are from work on the cylinder-piston compression design, which performed unsatisfactorily and was terminated. These references are summarized only briefly. The remaining references which are for the compression chamber/rubber cap/metal cup design, are summarised concisely but in sufficient detail that areas of investigation can be readily identified.

A. CYLINDER-PISTON DESIGN

- Ref. [7] First model, DRL Type 1. CE filling, trialled in bomb pistol No. 44 Mk III, results unsatisfactory.
- Ref. [8] DRL Type 2, used a cup shaped plunger sliding over a spigot for compression. Filling CE/PETN with a flash hole in the filling, flash hole dimensions and filling densities were investigated. Tested in 3 in mortar bombs by air dropping, all functioned.
- Ref. [9] As Ref. [8] but CE filling. Field trial was successful.
- Ref. [10] Review of development to date. Results for DRL Type 2 and Type 3 (plunger/cylinder design) with some optimisation of parameters. Type 2 fired from mortar, Type 3 air dropped. Significant number of blinds in both cases.
- Ref. [11] Further trial of Type 3, fired from 3 in mortar onto snow, and a Type 4 which differs by having a shorter CE stemming. Trial results variable.
- Ref. [12] The CI fuze development was now directed specifically to medium and heavy mortars. Final trial of Types 2 and 3, unacceptable incidence of blinds were observed. Small number of Type 3 Mod 1 forwarded to UK for testing, published as ARD Report 216/46. Work on Types 2 and 3 terminated for a Type 4 which had hydraulic compression. Note this is not the same as Type 4 in Ref. [20].
- Ref. [13] Experimental study aimed at determining the optimum density of CE in the stemming to achieve detonation. Ignition under static condition by electric primer, with output determined by witness blocks. The optimum density was found to be 1.35-1.45 g/cm³.

- Ref. [14] Study analogous to [13] using RDX. Optimum density found to be 1.15-1.35 g/cm³.
- Ref. [15] Early static laboratory testing on the Type 1 Fuze, using both drop weight and electrical initiation.
- Ref. [16] A related British system ignited by gunpowder, with an RDX stemming of comparable physical parameters. The RDX density, diameter length, flash hole diameter and confinement were all varied. The optimum RDX density was found to be 1.10 g/cm³ and must be less than 1.5 g/cm³.
- Ref. [17] Describes an experimental study to elucidate the mechanism of action of the Type 3 Mod 1 fuze.
- Ref. [18, 19] British Study into the mechanism of the Type 3 Mod 1 Fuze.

B. RUBBER CAP/METAL CUP/CONICAL AIR CAVITY DESIGN

- Ref. [20] Follows on from Ref. [15]. The first half of this report concerns further investigations on the piston/cylinder model. It was concluded that this design was not worth pursuing further, mainly due to the high rate of blinds at low strike angles and low velocity. The first fuze design, the Mould Type 4, incorporating a cone shaped air cavity with a rubber cap and metal cup, is introduced. Initial tests modifying the Mould Type 3 to this system were successful in field trials. Experimental variables examined on the Type 4 included volume of air in the compression chamber, depth of cavity in the filling, assessed by drop weight sensitivity. The priming was CE/PETN (1:1), density 1.50 g/cm³, and CE, density 1.35 g/cm³, in the stemming. Both steel and duralumin were examined as materials for the cup, and a number of rubbers were tested as the cap material, the final choice being neoprene A35.
- Ref. [21] Derivation of the Type 4 Mark 3 Fuze. Basic design features are described.

Initiator Body (Mould): Brass. The flash hole was varied; it was found that the smaller the flash hole the better the performance, and a length of 1/16 in was finally chosen as a compromise with ease of production. The diameter was also varied in trials.

Cap and Cup: The cap material was chosen to be neoprene A35 on the basis of good plasticity at low temperatures. Cup materials of steel, brass and aluminium gave little performance differences and the latter was chosen on the basis of availability.

Cavity in the explosive filling: Determined by the flash hole dimensions. Best results were obtained by forming with a spigot during pressing, while drilling gave inferior performance and functioning did not occur in the absence of a cavity. A cavity length of 1/4 in gave best laboratory results but 7/64 in was finally chosen for ease of production.

Nose: Concave, with a diaphragm closing the inner end of the cavity to prevent functioning on light targets and during handling. Trials with the diaphragm flush with the nose and set down 1/4 in revealed a high degree of blinds in the former, due to failure of the diaphragm to shear. This was attributed to poor flow of target material in front of the projectile. Further trials with the nose set back 1/4 in and 1/2 in showed no difference, and it was considered that the deeper setting gave greater safety and was chosen for future trials.

The first trial used a 1 in diam. diaphragm and the fuze was fitted to 3 in mortar rounds and fired against a variety of targets. A low rate of EO and blinds was observed for all targets except sand. A parallel development with a diaphragm of reduced diameter for improved safety on firing through light targets gave similar results. A later trial at the same area (marshland) gave a high incidence of blinds; examination of recovered rounds suggested that failures were caused by the now dry fine dust surface consolidating excessively in the nose cavity and reducing the speed of diaphragm depression. Shell grit and coarse sand gave similar results.

Diaphragm: Designed so that on plastic targets the target material would enter the nose cavity, shear the pins when sufficient pressure had built up, and force it in at high speed deforming the cup and forcing the cap into the compression chamber. On hard targets collapse of the nose and fuze body would carry the diaphragm forward onto the cup. Initially the diaphragm was a light alloy disc secured by three 16 gauge copper pins, push-out load 270 lb, and performed satisfactorily. To ensure non-function against foliage and light targets, the push-out load was increased and field trials indicated 2000 lb to be acceptable. This was adopted for future trials.

Body: Undercut internally so that it would crush against hard targets, but strong enough to withstand Service rough usage. 1/16 in wall thickness was originally chosen but deformed excessively when bombs were dropped nose first. This was increased to 3/32 in and functioned satisfactorily against targets while giving adequate safety from dropping. No attempt was made to optimise this parameter.

Safety and Rough Usage Trials: Passed all Ordnance Board schedule trials. When packed in boxes did not get sympathetic detonation or initiation when dropped from an aircraft. Initiation from blast, fragmentation and rifle bullet tests only occurred if there was a direct hit on the diaphragm or the blast pressure exceeded the push-out load. Cook-off at 800°C > 4 min. No apparent

compatibility problems. The fuze initiated if it struck a hard object near the muzzle (3 in mortar) but not a soft object. Double loading would probably result in functioning upon firing. There still appeared to be a large margin of safety to set-back even if the fuze was mal-assembled by failure to insert the shear pins.

Ref. [22] Progress report to the end of 1960, commencing with a general review of the CI concept then a description of progress to date on its application to service weapons. These included:-

Fuze DSL Type 4, Mk3 for OML 3 in mortar (WANDELLA): The aim was to meet Army specification for non-function on foliage but function on hard objects. Acceptance trials for Army occurred in late 1958 and continued till April 1959. Functioning was satisfactory except when fired at reduced charge and onto hard meadowland and snow. A number of modifications were then made:

1. Nose rim reduced from 3/16 in to 1/16 in and nose profile changed to allow more rapid target penetration. This also resulted in improved range.
2. Reduction in the diaphragm push-out loading from 2000 lb to 1000 lb; this was shown not to compromise safety.
3. Addition of a plastic insert in the nose cavity to minimise angular diaphragm movement following rupture and prevent loss of energy.

Firing trials indicated improved overall performance and further trials were being undertaken.

Fuze for Field Branch Artillery (MANDURANG): Similar to Wandella in using the same initiator but of reduced dimensions for improved ballistic performance. Trials were conducted to establish safety and all tests were passed, no prematures were observed. An initial firing trial was carried out with mixed results and more were planned.

Fuze for 40 mm Ammunition: Preliminary trials were satisfactory and further development was planned.

Bomb, Aircraft, Practice, 25 lb: The main thrust was for lower fire hazard following burst. The first design gave no significant improvement, but modifications for a future development are described.

Bomb, Aircraft, 1000 lb HE: Both the 25 lb practice and 1000 lb HE used the Wandella fuze. Description of future applications is detailed.

Background R&D

A number of topics are described here. A hydraulic operating mechanism, with fluid surrounding the initiator cup (instead of

air), was found to function satisfactorily in field trials. It was claimed that the major advantage is the ease with which the system can be made safe. The use of plastic materials, particularly in the nose section, which could lead to substantial cost savings is discussed. The results seemed to be encouraging and were to be pursued. Mention was also made of experimental work to measure time intervals between impact and detonation and pressure/time characteristics. These are described in more detail in later reports.

Ref. [23] Derivation of the drop-weight test for determination of sensitivity to initiation and whether detonation had been achieved in XF1 and XF2 initiators. Full experimental details are given.

Ref. [24] Development of a donor power performance test for inclusion in the drop-weight sensitivity tests for CI fuzes. XF2 Initiators were used, filled in a variety of non-standard ways to imitate factory filling variations. Flash hole 0.06 in long, 0.040 in diam., normal priming high density increments pressed at 620 lb to density 1.69 g/cc, total length 0.30 in, then low density increments pressed at 62 lb, density 1.43 g/cc, total length 1.45 in. Experimental initiators were filled with sieved grade 1A RDX and had 1-4 high density increments. Ionization and pressure probes were fitted, witness blocks of mild steel were used.

Results/Disc 1. 1-3 h.d. increments gave maximum dent on the witness block while probes showed that 2-3 were necessary for build up to stable detonation. Variation in time to traverse the priming charge was fairly wide but very narrow over the stemming. It was concluded that functioning time variations derive from the priming increment. Depth of dent was found to be applicable for detecting gross anomalies in filling.

2. Bruceton 50% height (2 lb weight) determined as 8.6 ft, $\sigma = 0.1$ ft. Depth of dent the same as in part 1 (12 ft drop), implying that the initiation impulse is not significant for depth of dent.

3. Testing of initiators with paper disc or aluminium alloy stemming covers such as would occur from factory production gave no reduction in depth of dent.

4. Short fillings, with the initiators filled short by 0.06 in and 0.03 in. The former produced unacceptably small dents, the latter were OK. A short fill of 0.06 in should be readily picked up by inspection at proof.

Ref. [25] Second part of the study described in Ref. [24]. Initiators F2 were studied, the same filling variations were examined. Aluminium witness blocks were used. A combined drop-weight sensitivity/donor power output test was derived. This test could differentiate "standard" F2 with 2 h.d. increments from non-standard with 1-3 h.d. increments.

Ref. [26] This was a study designed to investigate why the initiators in climatically cycled fuzes exhibited substantially decreased dropweight sensitivity, but no apparent decrease in sensitivity when test fired in the field, and to devise a laboratory test method which matched field testing results. It was considered that the most likely difference between the drop weight test and field test against soil was the significantly longer duration of impact force in the latter. A number of modifications were made to the laboratory drop weight test equipment to increase the duration of the impact pulse. Most modifications failed because the ISAT(B) cycled fuzes were not initiated or were substantially less sensitive c.f. usual drop weight test. A test equipment consisting of a primary plunger with a secondary plunger gave a fourfold magnification of impact velocity. Under these conditions both normal and aged fuzes had similar sensitivities. This was to have been followed up by a field trial but it either was not performed or not reported.

Ref. [27] An experimental study aimed at

1. Measurement of time from initiation of RDX to the detonation wave reaching the end of the stemming.
2. Finding the position in the stemming where detonation commenced.
3. Checking whether full detonation is achieved at the end of the stemming.

Brass (XF1) initiators were used with ionization and pressure probes fitted to the fuze body after filling with RDX.

Results/Disc 1. Time from ignition to the detonation reaching the end of the stemming was 24.2 μ s, range 20.1 - 28.3 μ s.

2. Detonation commences 0.8-1.0 in from the top of the stemming.

3. Mean V of D over final 0.7 in of stemming was 7600 m/s; range 6500-8500 m/s. Total length of stemming was 1.7 in hence it was quite adequate for build up to detonation.

Ref. [28] Laboratory experiments on CI "detonator" using drop weight experiments.

1. Functioning time and velocity of impact was measured, cap/cup compression was physically limited in some cases. Two towers were used, 400 lb/30 in max, 10 lb/38 ft max. It was found that functioning time \propto 1/impact velocity, with the major part of the functioning time of the device being collapse of the cup and cap. Once ignition occurred, the time taken for the stemming to detonate was very small. The cup/cap must be compressed at least 0.20 in in a time $<$ 5 ms to function.

2. Design and material of the cup/cap and the mechanism of collapse of the hemispherical cap were investigated. Both hemispherical cup and truncated cups, of brass or dural, were tested. The truncated cup/cap gave shorter functioning time. Mechanism of collapse of the hemispherical cup/cap is given, supported by rather crude radiographs; suggests that the cap rubber is forced into the cone and flash hole, raising the air pressure till ignition occurs.

3. Mechanism of initiation

- a. adiabatic compression of air under cup/cap.
- b. initiation by shock waves generated in the air by the high speed jet of rubber from the cap.
- c. ignition by heat from the friction of the rubber as it rubs down the cone and flash hole.
- d. stab initiation - the rubber jet moving down the flash hole should be quite rigid.

Various experiments were conducted to isolate particular mechanisms. Conclusion was that at slow compression rates mechanism a. operates, while a. and b. operate at high compression rates.

Ref. [29] First trial, 81 mm mortar.

Aims: 1. Establish a card test to assess the performance of Fuzes PD SQ XF7 cf. Fuze 162, fired at charges 8,4,1.

2. Fuzes PD SQ XF7 modified to alter drop weight sensitivity were assessed for field performance.

Results/Disc 1. The test was found to be feasible, large differences between XF7 and conventional 162 fuzes were observed. The former were much less sensitive at low impact velocities. The sensitivity of XF7 varied significantly with impact velocity.

2. Modified XF7 fuzes showed that high velocity impact sensitivity had little correlation with drop-weight sensitivity; mechanism different in the two cases? Replacement of air ($\gamma=1.4$) by propane ($\gamma=1.1$) substantially diminished drop-weight sensitivity (implying compression ignition) but had no effect on field testing. It was suggested that field (high velocity) testing may merely measure the energy necessary to shear the diaphragm (which is not present in the drop-weight test).

Note: Sensitivity of Initiator XF2 increased (to drop-weight) by; replacement of neoprene DS 300E plug with silicone rubber (silastic, S6508), reduction of both 0.040 in diameter flash hole and cavity in explosive to 1/32 in, or replacement of Australian

Grade 1A sieved RDX by British Grade 1 recrystallised RDX.

Ref. [30] Second trial (ED 66/1), 81 mm mortar.

Aims: 1. To assess the sensitivity of Fuzes F7/F2 having an acceptable drop weight sensitivity.

2. Determine, in terms of field performance, the significance of the decrease in drop weight sensitivity resulting from ISAT(A) storage.

3. Assess functional ability of Fuzes PD SQ F7 Lot 1 ME 1/64 forwarded to USA for evaluation, which reportedly performed unsatisfactorily against pressed fibre and plywood targets.

4. Obtain information on fuze performance on the variable thickness card and 3/4 in plywood target by high speed photography. Also tested: Initiators F2 with evacuated chambers, and Initiators F2 and EDI 3 with polyethylene coated RDX as the priming filling.

Disc/Results 1. Fuze F7/F2 controls, fuzes subjected to 3 months ISAT (A), and Lot 1 ME 1/64 supplied from US trial all performed comparably despite having a wide range of drop-weight sensitivity. Fuze F7 with a modified RDX/polyethylene filling, and Fuze F7/EDI 3, also performed similarly. This suggests that the mechanism of initiation at high velocity is different to drop-weight e.g. shock vs adiabatic compression, or alternatively that field testing only measures the condition necessary to shear the nose diaphragm and once this happens even less sensitive initiators function.

2. Fuzes with evacuated noses, drop-weight sensitivity > 10 lb/40 ft cf 2 lb/8 ft normally, don't function at charge 1 with normal cardboard thickness.

3. Fuze F7 Lot 1 ME 1/64 functioned on plywood target at 770 fps but not 650 fps (high speed photography). Some details from the US trials are listed in Appendix 1.

Ref. [31] Third trial (ED 66/2), 81 mm mortar.

Aims: 1. Assess by card-gap test the performance of Fuzes F7/F2 having evacuated compression chambers.

2. Assess approximate sensitivity of Initiators F2 and EDI 2, with both RDX and PETN fillings. Fuze F7 requires large card thickness to function at charge 1 and fails at charge 0, implying suspect nose design. The EDI 2 and PETN were required background information for Fuze XF8.

3. Assess performance of F7/EDI 3 at ambient and -5°F onto meadowland. Note that under static test conditions the EDI 3 has significantly larger indentation power for equivalent weight of RDX in a shorter stemming (0.6 in shorter) than F2, possibly due to

favourable density increments in the tapered EDI 3 stemming.

Disc/Results 1. The card thickness for 50% initiation of Fuze F7/F2 with evacuated chamber, at charge 4, is significantly greater than normal F7. Since the fuze still functions, this suggests a mechanism other than adiabatic compression eg. shock, at high velocities. The significant difference between 50% values at charge 1 for Fuze F7 and its component initiator demonstrates that lack of sensitivity at low impact velocities is predominantly associated with nose design; conclude this is the major problem for low velocity functioning. Initiators F2 and EDI 2 exhibit very similar sensitivity.

2. Initiator EDI 3 at charge 1/ambient/meadowland performed satisfactorily with 0.90 g RDX in the low density increment but not 0.93 g(?). It was suggested that the latter was due to set-back. Both were unsatisfactory at -5°F. Fuze F7/EDI 3 (silicone caps) achieved 90% functioning at charge 1/-5°F/soil cf. 20% for F7/F2 (neoprene caps) at charge 1/-5°F/sand.

Ref. [32] Fourth trial (ED 66/3), 81 mm mortar

Aims: 1. Assess effects of set-back forces on Fuze F7/F2 with silicone caps, fired at charges 1 & 8 at -5°F.

2. Assess performance of the initiator and gaine proposed for use in Fuze XF8 by assembling bumped components into Fuzes EDF 7 (used for comparison with Fuze F7) and XF8.

3. To gain further information on the functional ability of Fuzes PD SQ F7 Lot 1 ME 1/64 (as forwarded to USA for evaluation).

4. Assess in terms of field performance the significance of the decrease in drop weight sensitivity of Initiator F2 resulting from ISAT(B) storage, in Fuze F7.

Disc/Results Fuze F7 containing silicone caps functioned reliably at charges 1 & 8 at -5°F onto meadowland. It was concluded that set-back was not significant since indentation into a witness block was similar for both firing charges and comparable with Initiator F2 under drop weight testing. Silicone caps gave the highest sensitivity. The initiator/gaine combination proposed for the XF8 functioned reliably in the EDF 7 at -5°F/charge 8/meadowland, producing indentation comparable with a static drop-weight test, but 20% developed less power at charge 1. However this is better than EDI 3; conclude that the length of stemming in the gaine is marginal under the latter conditions. The design of the nose in Fuze XF8 is unsatisfactory. Fuzes F7 Lot 1 ME 1/64 exhibited 90% functioning at charge 1/45°F/meadowland cf 97.5% (75 tested) for Fuze F7 under the same conditions. Fuze F7/F2 following 2 weeks ISAT(B) functioned reliably at charge 1/ambient, indistinguishable from control Fuze F7. Drop-weight testing does therefore not mirror field testing.

Ref. [33] First trial of delay fuze, 81 mm mortar

Modification of an earlier SQ fuze (XF1) to a delay fuze, required delay ~ 300 ms. Static trials gave delays of 250-400 ms when sealed (to mirror field trials) and 600-700 ms unsealed. Compared to Fuze SQ XF5 in field trials.

Results/Disc 1. SQ fuzes all functioned, but most delay fuzes failed. Recovery showed that initiation had occurred but the delay element had failed.

2. Modification of delay element improved performance with only 12% extinguished in the delay increment. Fuzes which functioned had delays > 600 ms, indicating venting.

3. A number of major modifications were made to give a delay of 60-100 ms on unsealed static testing. Field trials gave wide time variations from SQ-112 ms. It was concluded that the delay element was faulty. A different delay composition and pressing procedure was adopted, resulting in static trial times of 69-78 ms. Field trials gave delay times from SQ-116 ms but most within a narrower range. It was suggested that venting may vary upon impact and hence the times vary. A total of 56 delay fuzes were tested; one functioned SQ two just behind the target, and three were blind of which two recovered. One blind resulted from non-functioning of the initiator.

Ref. [34] Second trial of delay fuze (trial SPE 436/3)

The aims of this short trial were to establish the reasons for unsatisfactory performance of the delay fuzes Types 2A and 2B when fired in 25 pr. ammunition at supercharge and the extent of nose break-up on impact. Several Fuzes PD SQ XF5 containing Initiators XF1 modified in ways known to affect drop weight sensitivity were also tested.

Results/Disc 1. Unsatisfactory performance of the delay fuze noted in the earlier study could not be achieved. Fuze XF5 with initiator and gaine (no delay) all functioned on target.

2. Satisfactory performance was observed at charge 1 but only Type 2A functioned with a consistent delay. Laboratory trials of Initiators XF1 modified by venting or substitution of air by propane in the compression chamber showed that drop weight sensitivity was lowered but neither change affected field performance.

3. Photographic aspects of the trial were unsatisfactory.

Ref. [35] Climatic testing of XF1 Initiators

This study followed from an earlier trial where PD SQ XF5 Fuzes, subjected to 6 months ISAT(A), were found to have developed

significantly decreased sensitivity to drop weight. Similar results were obtained for other CI fuzes containing RDX grade 1A. The aim of the trial was to determine the reasons(s) for the deterioration on ISAT storage.

Trial 1

The XF1 Initiators were divided into four lots: those assembled with cups, caps, stemming covers and with/without RD 1286 cement sealant, and those assembled with cups, stemming covers and with/without RD1286 but no caps. Only neoprene caps were used, and both Grade 1 and 1A RDX was used. All samples were packed into sealed ammunition boxes and subjected to ISAT(A) storage.

The initiators were examined after 6 months. The conical surfaces had discoloured in fuzes containing caps but microscopic examination revealed no deposits. Examination of the cavities in the explosive filling yielded no detailed information (radiography unsuccessful) but appeared normal; samples of RDX scraped from the cavity surface revealed no contaminants. The cavity volume was qualitatively unchanged but reforming the cavity by pushing in the spigot could restore some of the lost drop weight sensitivity from storage. Examination of the air in the compression chambers by mass spectrometry revealed no contaminants.

Drop weight sensitivity had decreased markedly after 6 months and at 12 months was near the maximum drop height (40 ft). Fuzes assembled without RD1286 showed less desensitisation, and those without caps less again, although in the latter case the cup had to be removed to fit a cap prior to testing. RDX and caps stored separately functioned normally when filled and assembled into initiators. If seriously desensitized initiators had the cap and cup removed then refitted, hence changing the atmosphere in the compression chamber, some of the lost sensitivity was restored. However the extent of the recovery decreased upon increasing storage (2 mechanisms?). It was concluded that loss of sensitivity was caused by change in the atmosphere of the compression chamber, and with a physical or chemical change in the RDX at the surface of the cavity or to a dimensional change in the cavity. RD1286 caused desensitization by contamination of the chamber atmosphere.

Ambiently stored control initiators showed only small sensitivity decreases after 6 and 12 months, and thus would normally be expected to undergo little change after 2 years.

Trial 2

To assess whether deterioration of the sealed fuzes was due to contamination by RD1286 or the fact they were sealed. Initiators XF1 were filled with RDX Grade 1, 1A and 1A precipitated from acetone, and assembled with neoprene and silicone caps, and sealed by RD1286 or asbestos.

Results/Disc Grade 1 RDX initiators were unaffected by ISAT(A) storage but Grade 1A and precipitated RDX were desensitized to

approximately the same extent as unsealed initiators. Replacement of the air in the compression chamber of desensitized initiators did not improve sensitivity, indicating the sensitivity decrease was associated mainly with the filling. No significant difference was found between Grade 1A RDX filled initiators with neoprene or silicone caps.

Trial 3

Repeat of trial 2 but only neoprene caps were used. Eastman 910 or neoprene rubber O rings were used for sealing, and some initiators were unsealed. All were screwed into fuze bodies.

Results/Disc After 6 months ISAT(A) the air in the compression chamber was sampled and assayed by mass spectrometry. The Eastman sealed samples had no contaminants but a very low oxygen/nitrogen ratio, while the unsealed fuzes were normal indicating that the compression chamber can breathe even when screwed into fuze bodies. The conical surfaces were only lightly stained and the caps and flash holes were normal, unlike that observed in Trial 1. Initiators remaining from Trial 1 were reexamined and the compression chambers were found to be similarly low in oxygen. Preliminary studies showed that oxygen was removed from a sealed air system by both neoprene and silicone caps at 140°F, more so with the former.

The drop weight sensitivity of the sealed initiators deteriorated much faster than those unsealed. Eastman or O-ring sealing produced similar desensitization, but much less so than RD1286 in Trial 1, hence this was the major cause of deterioration in Trial 1. It was concluded in this trial that reduction in oxygen concentration was the major cause of loss of sensitivity, but whether this was due to oxygen or total pressure reduction was not known. It was also concluded that some degree of desensitization was associated with the explosive filling in the region of the cavity but the nature of this was undetermined. Note that the RDX Grade 1 which was less desensitized was 20 years old (ex UK) and may not be representative of new production.

Appendix Results of field trials of ISAT(A) aged XF5 and XF3 Fuzes. It was concluded from Trials 1-3 above and field trials that the decreased sensitivity was due to decreased thermal sensitivity of the RDX cavity in the priming due to either occluded acid in the RDX or plasticiser from the cap. A discussion of cap materials is given, but only for neoprene (not silicone) type.

- Ref. [36] Investigation of increased malfunction in service of Fuze PD F7. A sample of thirty 81 mm HE M374 A2 w/fuze F7, 10 each from storage in 3 depots, were tested. All were lot 50 ME 10/70 which implied that they were roughly 6 years old. All fuzes appeared to have suffered no deterioration, were broken down and the initiators tested. Radiography showed the caps and RDX stemming was normal. Drop weight sensitivity was normal (M50% 8.14 ft) but depth of dent a little low (av. 0.096 in cf specification 0.100 in). It was concluded that the functioning test was failed.

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