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REPORT NO. R-627

HIGH SPEED X-RAY PICTURES OF THE FUNCTIONING
OF 20 MM H.E.I. SHELL N 97 (T23) WITH FUZE P.D. T71E4

FIRST REPORT

PROJECT: 2/148

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OBJECT

To take a series of high speed X-ray pictures showing the functioning of 20mm H. E. I. Shell M97 (T23) similar to the studies carried out for the 20 mm H.E.I. Shell MK-I.

SUMMARY

A series of high speed X-ray pictures have been taken which show the functioning of 20mm H.E.I. Shell M97 (T23) with Fuze P.D. T71E4 when fired through the following thickness of target plates: .012 in., 1/16 in., .083 in., 1/8 in. and 1/4 in. The pictures show the time of function, the manner of fragmentation of the shell and the formation of the hole in the plate.

At a striking velocity of approximately 2850 f/s against target plates placed normal to the line of fire the functioning of the shell is dependent on the thickness of the plate. Against .083 in. plate all shells functioned while passing through or after having passed through the plate. When fired against 1/8 in. and 1/4 in. plates the shells consistently functioned and ruptured before the bourrelets of the shells had passed through the plate. None of the shells fired against the .012 in. plate functioned. When fired against the 1/16 in. plate the shells frequently did not function until they were completely through the plate. Two shells out of 20 fired did not function at all.

The dependence of the functioning of the shell on the angle of impact and on velocity was observed on .083 in. plates. When fired at a striking velocity of approximately 2850 f/s against the plate inclined at 20° to the line of fire all shells functioned consistently and ruptured before having passed half way through the plate. Against a plate placed normal to the line of fire the shells frequently passed completely through the plate before functioning. When fired at 1600 f/s against the plate placed normal to the line of fire eight shells out of 35 fired did not function at all.

The shells swell to almost twice normal diameter before rupture is visible.

The explosion imparts a radial velocity of approximately 2800 f/s to the shell fragments.

AUTHORIZATION

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I. INTRODUCTION

This Arsenal has taken high speed X-ray pictures which show the functioning of 20 mm H.E.I. Shell MK-I, with Fuze No. 253 MK-II, when fired through a mild steel target (1/16 in. and 1/8 in. thick) placed normal to the line of fire. The pictures show the manner in which the shell ruptures and the formation of the hole in the target plate.⁽¹⁾ A request was received from the Office Chief of Ordnance to conduct similar studies for the 20 mm H.E.I. Shell M97 (T23).⁽²⁾

II. METHODS

A. Weapon

A 20 mm gun tube AN-M2 was used for the firing. An adapter sleeve was screwed on the breech end of the tube. This sleeve was threaded for the "A.E.S." screw-on firing action permitting convenient single round firing.

B. Ammunition

20 mm H.E.I. Shell M97 (T23) with Fuze P.D. T71E4 were used for these tests. A stationary radiograph of this shell is shown on Figure 1.

C. Targets

Mild steel plates (WD 1010 hot rolled annealed and pickled, or cold rolled, dead soft temper) were used as targets. The following target plates were used:

- (1) .012 in. x 12 in. x 16 in. placed normal to the line of fire.
- (2) 1/16 in. (.063 in.) x 12 in. x 16 in. placed normal to the line of fire.
- (3) .083 in. x 12 in. x 16 in. placed normal to the line of fire.
- (4) .083 in. x 12 in. x 36 in. inclined at 20° to the line of fire (70° between the trajectory and the normal to the plate).
- (5) 1/8 in. (.125 in.) x 12 in. x 16 in. placed normal to the line of fire.
- (6) 1/4 in. (.250 in.) x 12 in. x 16 in. placed normal to the line of fire.

The shells were fired at a striking velocity of approximately 2650 f/s through each of the above targets and also at a reduced velocity (1600 f/s) through the .083 in. target placed normal to the line of fire. A new target plate was used for each shot. The target was located 25 ft. from the muzzle of the gun.

Frankford Arsenal Ordnance Laboratory Report No. A-400, "High Speed X-ray Pictures of 20 mm H.E.I. Shell MK-I" by E. H. Thilo

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D High Speed X-Ray Pictures

The high speed X-ray equipment (3) was used in taking the pictures. A picture showing the arrangement of the X-ray tubes and film with respect to the target and fragment protection is shown on Figure I of Frankford Arsenal Ordnance Laboratory Report No. R-480.(4)

A number of shells were fired through each thickness of plate and high speed X-ray pictures were taken at the instant of impact and at varying times thereafter.

For the targets placed normal to the line of fire two mutually perpendicular high speed X-ray pictures were taken of the functioning of each shell. A diagram of the set-up used in taking these pictures is shown on Figure 3 of Frankford Arsenal Ordnance Laboratory Report No. R-480.(5) The line of fire was varied from 2 in. to 4 in. above the horizontal film cassette. Maximum detail of the functioning of the shell was obtained on this horizontal film. The mutually perpendicular picture was taken on the vertical film. This film was located 9 in. from the line of fire and the pictures obtained on this film are lacking in detail. However the failure of a shell to function such as round 18 on Figure 5 was revealed by this vertical picture.

In the case of the .083 in. target inclined at 20° to the line of fire only a single high speed X-ray picture was taken of the functioning of the shell. The horizontal tube and film cassette arranged as shown on Figure 3 (side view) of Frankford Arsenal Ordnance Laboratory Report No. R-480 (6) were used.

All high speed X-ray pictures were taken at 360 kilo-volt peak and using Patterson #245 industrial combination intensifying screens with Eastman Blue Brand Ultra Speed X-Ray Film.

III. RESULTS AND DISCUSSION

Representative prints of the X-ray pictures are shown on the figures that follow. These were selected from a large number of pictures not herein reproduced. The descriptive material accompanying the pictures is based on an examination of the original negative and some of the details have been lost in the reproduction process.

(3) Frankford Arsenal Ordnance Laboratory Report No. R-189, "High Speed X-Ray Equipment" by E. K. Thilo and C. M. Hudson

(4) Ref. 1, loc. cit.

(5) Ref. 1, loc. cit.

(6) Ibid.

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The pictures shown on Figures 2, 5 and 19 are direct prints from the X-ray negatives. The pictures shown on Figures 3, 4, and 6 to 18 inclusive have been copied from direct prints made from the X-ray negatives. The copied pictures have been reduced to approximately 1/3 size.

Figure 18 is included for comparing the manner in which the 20 mm H.E.I. Shell MK-I functions.

Two high speed X-ray pictures showing the fragmentation of 20mm H.E. Shell MK-III (Navy) (7) are shown on Figure 19.

Figure 5 shows two mutually perpendicular high speed X-ray pictures of one shell exploding with a time interval of approximately 44 microseconds between pictures. The average radial velocity imparted to the fragments by the force of the explosion was approximately 2800 f/s. This value agrees well with the values reported by Major Clark of Aberdeen. (8)

The X-ray pictures correlated with observations of the target plate revealed the following facts. Except where otherwise indicated the shells were fired at service velocity against target plates placed normal to the line of fire.

(1) .012 in. target plate (Figure 2)

(a) The shells did not function when fired through this thickness of plate.

(b) The windshields of the shells were not crushed up as a result of the impact.

(2) 1/16 in. (.063 in.) target plate (Figure 3, 4, 5)

(a) The shells frequently did not function until they were completely through the plate. Two shells out of 20 fired, did not function at all.

(b) The shells which did function while passing through the plate ruptured when more than half way through. This resulted in only small holes (2 1/8 in. maximum diameter) being formed in the plate.

(c) The 20 mm H.E.I. Shell MK-I (Fuze #253, MK-II) when fired through the same thickness of plate all functioned. Rupture of the shells consistently occurred before the shells had passed more than half way through the plate. A hole approximately 1 in. in diameter was formed in the plate. (9)

(7) Frankford Arsenal Ordnance Laboratory Report OR-70, "High Speed X-Ray Pictures of the Functioning of 20 mm H.E. Shell MK-II (Navy) when Fired Through 1/16 in. Mild Steel Target Placed Normal to the Line of Fire", by E. L. Thilo

(8) Aberdeen Proving Ground Ballistic Research Laboratory Report No. 3-9, "Final Report on the Use of 20 mm H.E.I. MK-I During the Battle of Britain" by L. J. Clark

(9) Frankford Arsenal Ordnance Laboratory Report OR-420, 1st. ed.

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(3) .083 in. target plate (Figure 6, 7)

(a) All shells functioned when fired through this thickness of plate.

(b) The time at which the shells functioned varied. Eight shells out of 32 fired passed completely through the plate before functioning.

(c) Shells which functioned and ruptured before passing half way through the plate produced large holes (6-7 ins. in diameter). The momentum imparted to the petals on the back of the plate from the force of the explosion caused them to curl back and form the large hole.

(4) .083 in. target plate, shell fired at reduced velocity (1600 f/s) (Figure 8, 9).

(a) Thirty-five shells were fired at reduced velocity through this thickness of plate. Two shells functioned after passing through the plate. Eight shells did not function at all.

(b) The other 25 shells functioned. Rupture of these shells consistently occurred before the shells had passed more than half way through the plate. These shells produced a large hole (6-7 in. diameter) in the plate.

(5) .083 in. target plate inclined at 20° to the line of fire. (Figure 10, 11)

(a) The shells all functioned consistently and ruptured before having passed half way through the plate.

(b) The explosion of the shells produced a hole approximately $2\frac{3}{4}$ in. in diameter in the plate. The momentum imparted to the petals on the back of the plate from the impact of the mushroomed shell base caused them to curl back and form a much larger hole ($4\frac{1}{2}$ ins. in diameter)

(6) $1/8$ in. (.125 in.) target plate. (Figure 12, 13, 14)

(a) The shells all function before passing through the plate.

(b) The shells start to swell approximately 74 microseconds after impact. Rupture of the shells takes place before the boreholes of the shells have passed through the plate (approximately 45 microseconds after impact).

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(c) The momentum imparted to the petals on the back of the plate from the force of the explosion caused them to curl back and form a large hole (6 - 7 in. in diameter).

(d) The 20 mm H.E.I. Shell MK-I (Fuze #253, MK-II) functioned in a similar manner when fired through the same thickness of plate. (10)

(7) 1/4 in. (.250 in.) target plate. (Figure 15, 16, 17)

(a) The shells all functioned before passing through the plate.

(b) The shells start to swell approximately 20 microseconds after impact. Rupture of the shells takes place before the bourrelets of the shells have passed through the plate (approximately 40 microseconds after impact).

(c) The momentum imparted to the petals on the back of the plate from the force of the explosion caused them to curl back to form a hole approximately 5 in. in diameter.

The shells swell to almost twice normal diameter before visible rupture takes place. The noses of the shell breaks up into fragments. In the case of the H.E.I. MK-III shell the noses of the shells remained in one piece. The fragmentation of the rest of the shells is similar to that of the MK-III shells (i. e. rupture of the shell body, mushrooming out of the base of the shell).

The fragmentation of the 20 mm H. E. Shell, MK-III (Navy), is different from the H. E. I. Shell in that the nose, body and base of the shells all break up into small fragments when the shells rupture.

IV CONCLUSIONS

The high speed X-ray pictures show the manner in which the shell functioned, the fragmentation pattern of the shell and the formation of the hole in the plate.

At a striking velocity of approximately 1850 ft/sec against target plates placed normal to the line of fire the functioning of the shell is dependent on the thickness of the plate used. Against .083 in. target plates all shells functioned while passing through or after having passed through the plate. When fired against thicker plates the shells consistently functioned and ruptured before the bourrelets of the shells had passed through the plate.

The functioning of the shell is dependent on the angle of impact. At a striking velocity of approximately 1850 ft/sec the shell is inclined at 45° to the line of fire. At this angle the shells consistently functioned and ruptured before having passed through the plate. When the plate is placed normal to the line of fire (10) Project: Artillery Research Laboratory Report No. 1-44, 1-45, 1-46.

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fire the shells frequently passed completely through the plate before functioning. The functioning of the shell is also dependent on the striking velocity. When fired at a striking velocity of approximately 1600 f/s against the plate placed normal to the line of fire eight shells out of 35 fired did not function at all.

In order to form a large hole in the plate the shell must function and rupture before it has passed more than half through the plate.

V. RECOMMENDATIONS

It is recommended that in the development of 20 mm Incendiary, H.E.I., and H. E. Shells that the functioning of these shells be studied by means of high speed X-ray pictures.

-6-

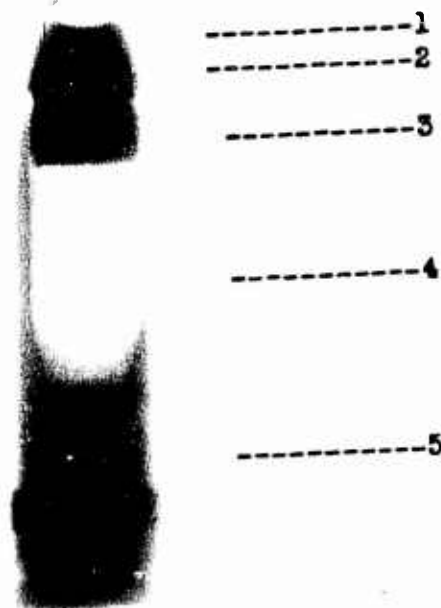
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Stationary X-Ray Picture of 20 mm. H.E.I.
Shell M 97 (T 23) With Fuze P.D. T 71 E 4

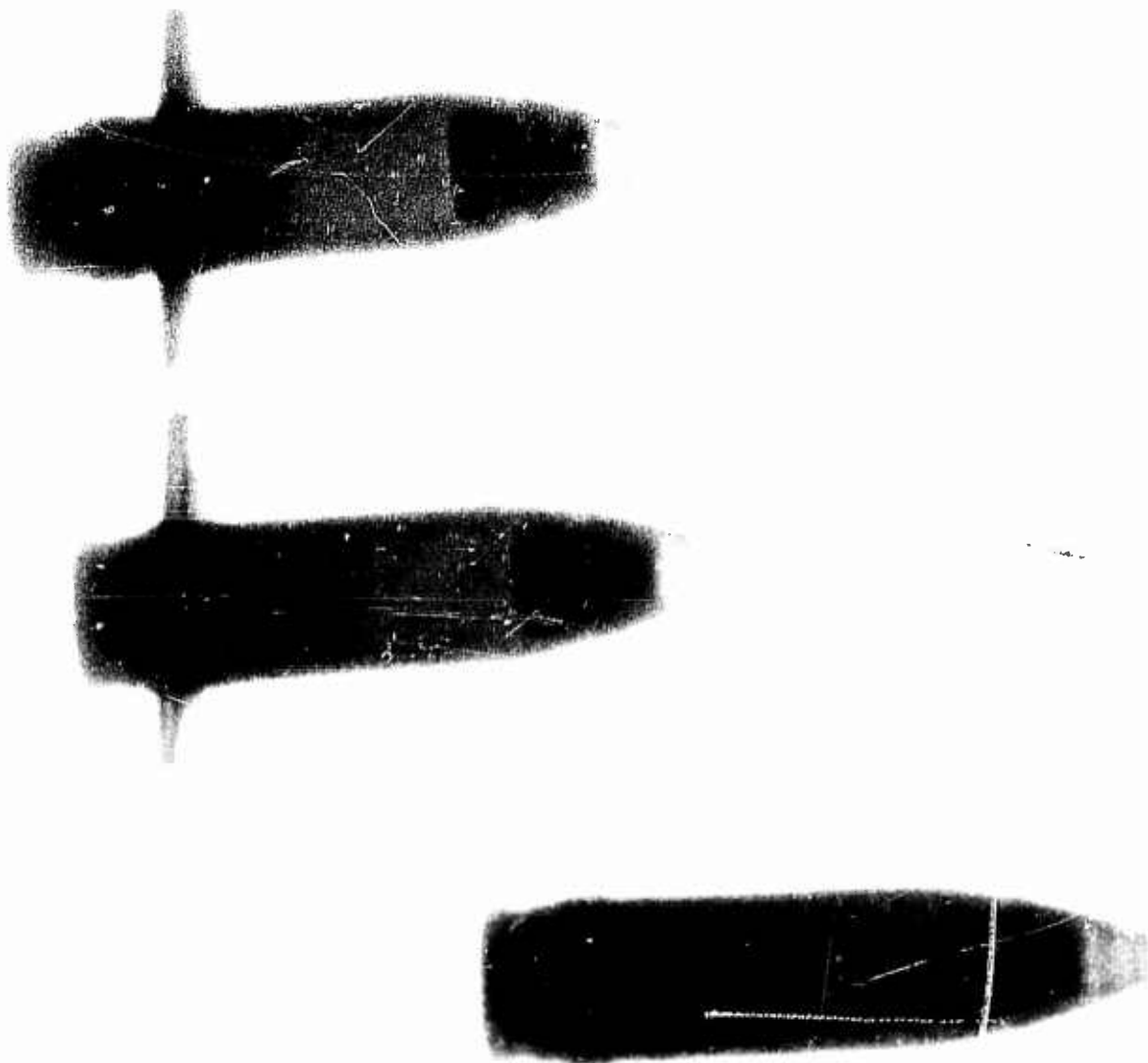
- 1 Detonator, Approximately 5.8 grains Mercury Fulminate
- 2 Lower Detonator, Approximately 2.69 grains Lead Azide
- 3 Magazine Charge, Approximately 2.9 grains Tetryl
- 4 Tetryl, Approximately 85.4 grains Tetryl
- 5 Incendiary Composition, Approximately 34.0 grains

REG. #15855-1

FIGURE 1

9 JUNE 1942

High Speed X-Ray Pictures of the Functioning
of 20 mm. H.E.I. Shell M 97 (T 23) when fired
through an .012 in. mild steel target placed
normal to the line of fire. Fuze P.D. T 71 E 4.

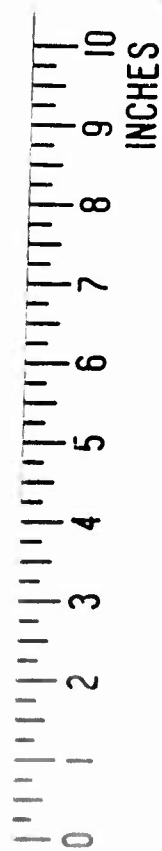


No crush up of the windshield as a result of the impact

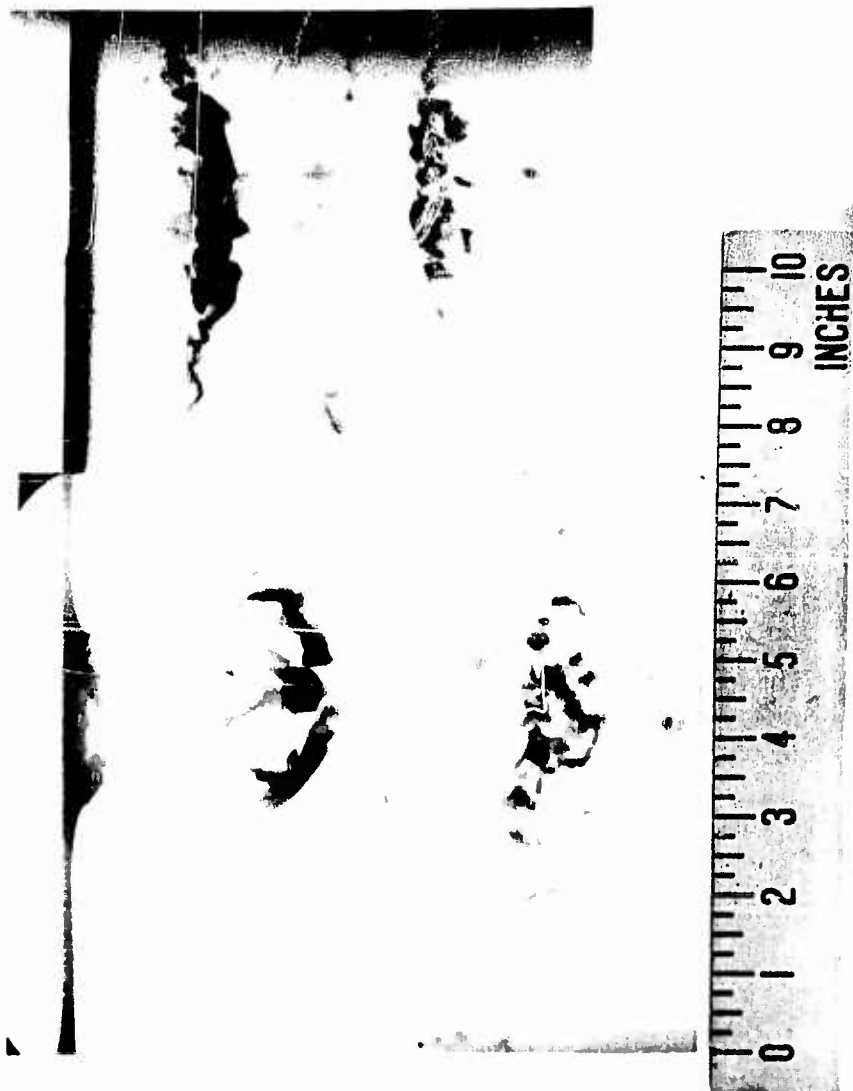
NEG. #15859-2

FIGURE 2

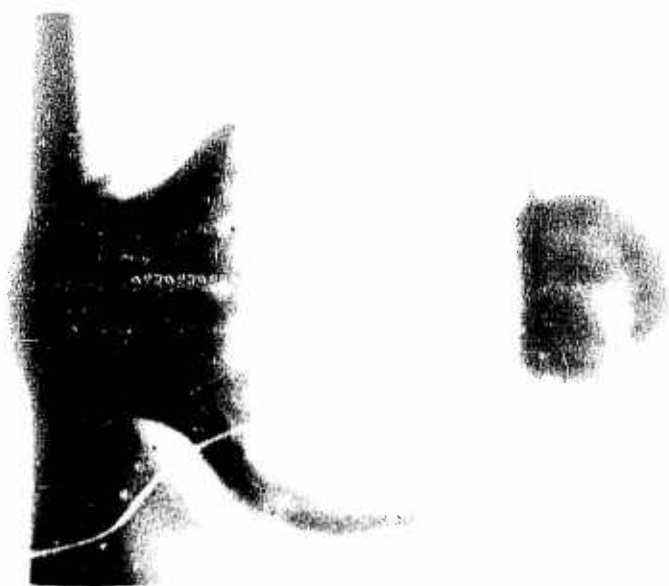
9 JUNE 1945



1. 100% A 100% HYDROLYZABLE AM. H.E.I.
2. 100% A 100% HYDROLYZABLE AM. H.E.I.
3. 100% A 100% HYDROLYZABLE AM. H.E.I.



High Speed X-Ray Pictures of the Functioning of 20 mm. H.E.I.
Shell M 97 (T 23) when Fired through a 1/16 in. mild steel
target placed normal to the line of fire. Fuze P.D. T 71 E 4



The shell ruptured
after it passed
through the plate.



Perpendicular picture of this shell taken approximately 44 microseconds later.

THE VENTRAL SURFACE OF THE SHELL WAS IN CONTACT WITH THE PLATE.

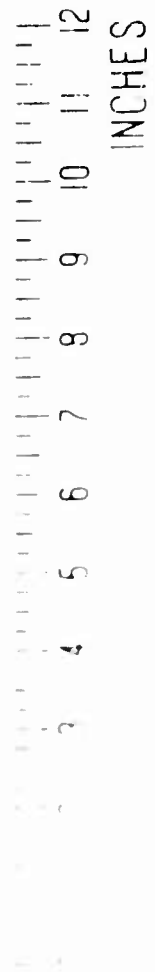
NOSE OF ANCHOR IN CONTACT WITH THE PLATE

THE NOSE OF THE SHELL WAS FACED TOWARD THE PLATE. THE ANCHOR HAD EXPANDED AFTER BEING CRUSHED UP.

THE SHELL BODY HAD SWELLED TO INTER-TAPER NORMAL DIAMETER AND RUPTURED. THE DETAIL HAD RETAINED THE DOUBLED-UP REGION OF THE SHELL FROM SWELLING AS RAPIDLY AS THE BODY OF THE SHELL. THE BACK OF THE SHELL HAD SWELLED VERY LITTLE.

THE SHELL BODY HAD STOPPED TO SWELL.

THE BACK OF THE SHELL HAD SWELLED TO INTER-TAPER NORMAL DIAMETER AND RUPTURED. THE DETAIL HAD RETAINED THE DOUBLED-UP REGION OF THE SHELL FROM SWELLING AS RAPIDLY AS THE BODY OF THE SHELL. THE BACK OF THE SHELL HAD SWELLED VERY LITTLE.

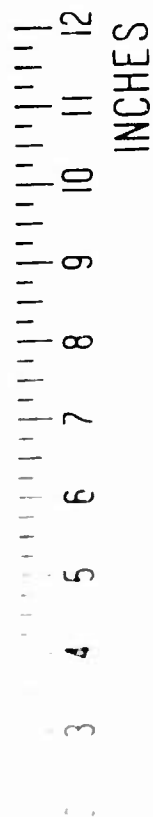


HIGH SPEED X-RAY PICTURE OF THE FUNCTIONING OF 20MM. H.E. I.
SHELL NO. 1111. WHEN FIRED THROUGH A 1/2 IN. MILD STEEL
TARGET PLACED NORMAL TO THE LINE OF FIRE. PHOTO 1111 F 4

THE FRAGMENT OF THE BACK OF THE SHELL ARE PASSING
THROUGH THE HOLE.

THIS SHELL PASSED COMPLETELY THROUGH THE PLATE
BEFORE IT FUNCTIONED. NO PETALS WERE FORMED IN
THE PLATE.

THE SHELL FRAGMENT ARE ALMOST ALL COMPLETELY
THROUGH THE BACK OF THE PLATE AND PASSING
THE PLATE.



1111

THE CHIEF BOY HAS GROWN TO BE THE SAME AS THE BOY WHO WAS THE FIRST TO BE SEEN AT THE CHIEF BOY'S HOUSE. THE BOY WHO WAS THE FIRST TO BE SEEN AT THE CHIEF BOY'S HOUSE.



HIGH SPEED X-RAY PICTURE OF THE PENETRATION OF 100MM. H.P.
 SHELL INTO A 1/2 IN. THICK STEEL TARGET PLATE NORMAL TO THE
 DIRECTION OF TRAVEL. THE SHELL IS SHOWN AT THE INSTANT WHEN IT
 IS PENETRATING THE PLATE. THE SHELL IS SHOWN IN TWO POSITIONS
 AT THE INSTANT WHEN IT IS PENETRATING THE PLATE. THE SHELL IS
 SHOWN IN TWO POSITIONS AT THE INSTANT WHEN IT IS PENETRATING
 THE PLATE. THE SHELL IS SHOWN IN TWO POSITIONS AT THE INSTANT
 WHEN IT IS PENETRATING THE PLATE. THE SHELL IS SHOWN IN TWO
 POSITIONS AT THE INSTANT WHEN IT IS PENETRATING THE PLATE.

THE BACK OF THE SHELL IS BREAKING UP INTO FRAGMENTS.
 THE FRAGMENTS ARE TRAVELING TO THE RIGHT.



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NEJ. #15684-4

FIGURE 9

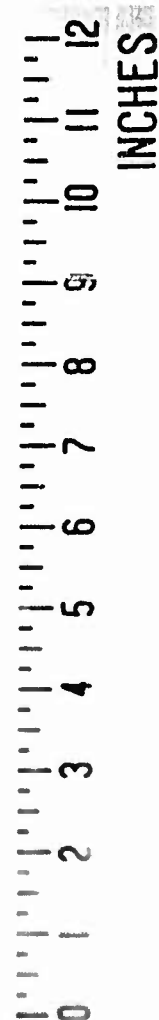
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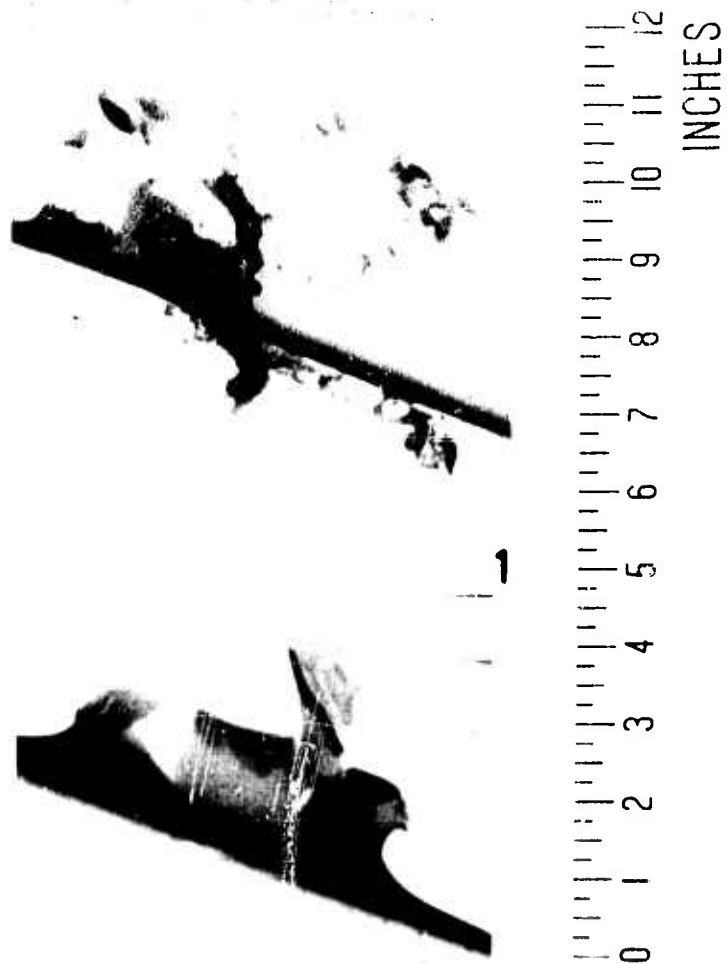
HIGH SPEED X-RAY PICTURES OF THE WINDSHIELD CRACKING AND THE SHELL BODY CRACKING THROUGH A 1/4 IN. MILD STEEL PLATE PLACED AT AN ANGLE OF 20° TO THE LINE OF FIRE. PHOTO 1 OF 10 P. 4

NOSE OF THE WINDSHIELD IN CONTACT WITH THE PLATE

THE WINDSHIELD HAS EXPERIENCED CONSIDERABLE CRACKING. THE SHELL BODY HAS CRACKED TO ALMOST TWICE NORMAL DIAMETER. THE RACE OF THE SHELL HAS CRACKED VERY LITTLE.

THE SHELL HAS CRACKED. THE BACK OF THE SHELL IS STARTING TO MUSHROOM INTO THE SHELL FRAGMENT. IN THE BACK SIDE OF THE PLATE ARE CRACKS DUE TO THE LATERAL AND FORWARD MOTION OF THE PLATE DURING

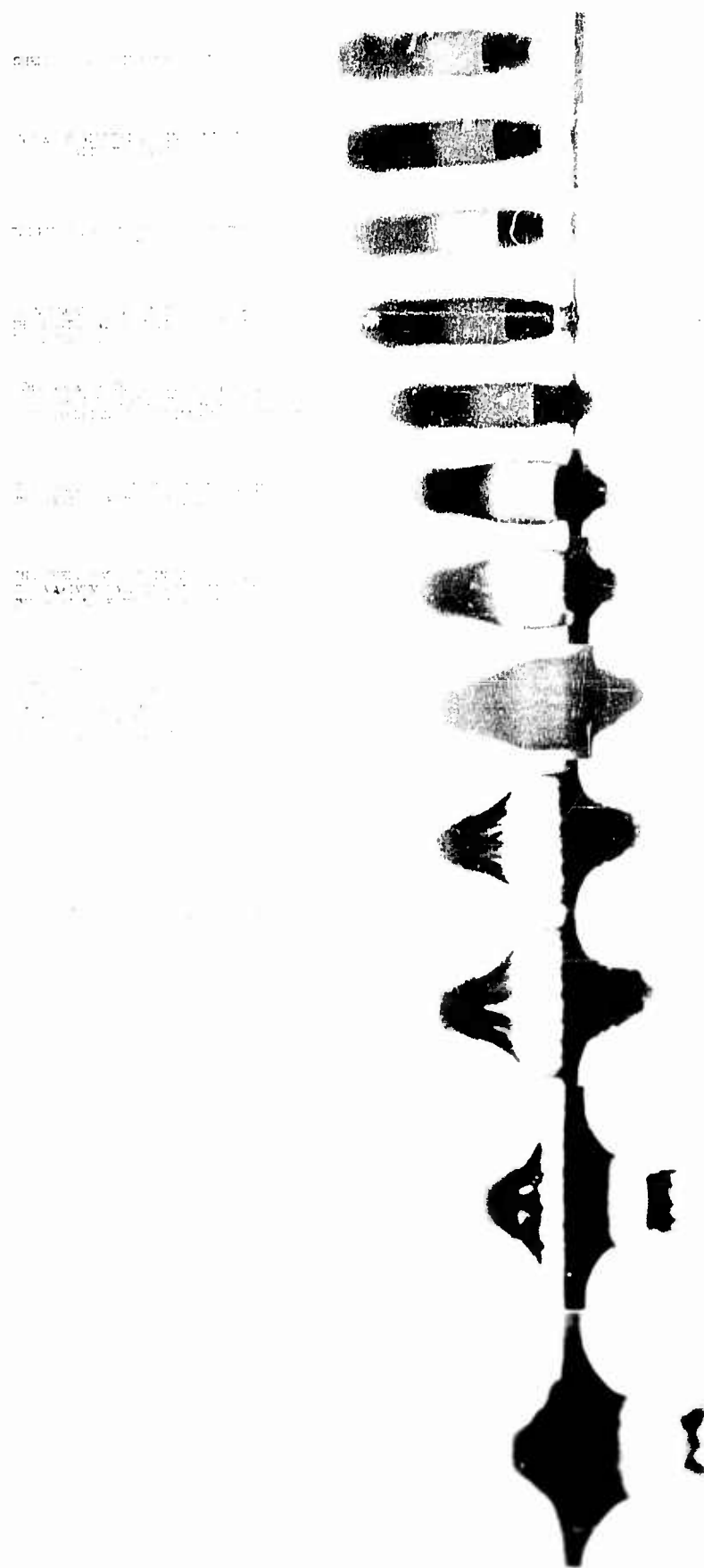




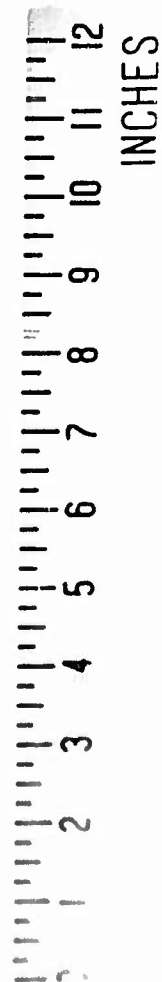
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FIGURE 11

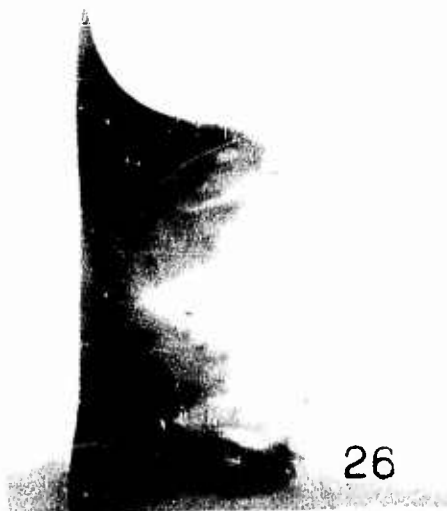
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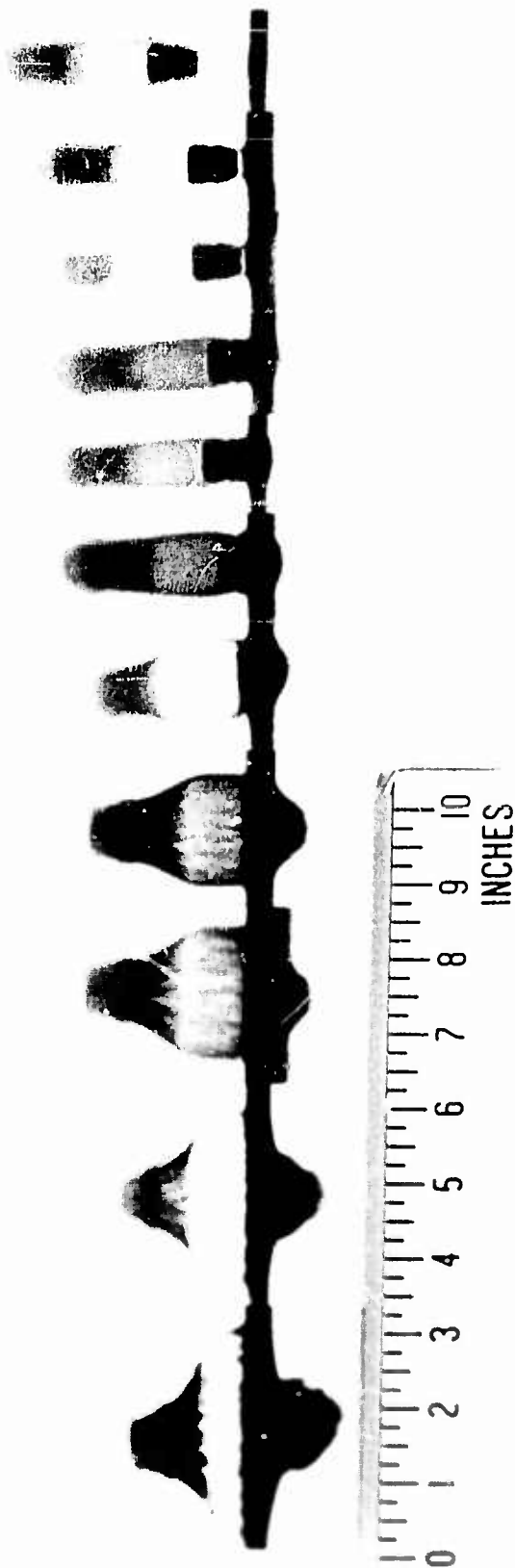
THE 11.50 AWAY INTEREST OF THE MARSHAL KING OF 20 MM. H.M.I.
 TRAILER OF 11.50 AWAY FIRST INTEREST OF 11.50 IN. AND OTHER
 TRAILER OF 11.50 AWAY TO THE 11.50 IN. MARSHAL KING OF 20 MM. H.M.I.



THE PETALS HAVE CULLED BACK TO PRODUCE
 A HOLE APPROXIMATELY 5/8 IN. IN DIAMETER.



HIGH SPEED X-RAY PICTURES OF THE FUNCTIONING OF 20 MM. H.E.I.
 SHELLS AT 1000 YARDS RANGE. FIRST PICTURE TAKEN AT 1/1000 INCH. SECOND
 PICTURE TAKEN AT 1/1000 INCH. THIRD PICTURE TAKEN AT 1/1000 INCH.



HIGH SPEED X-RAY PICTURES OF THE FUNCTIONING OF 20 MM. H.E.I.
SHELL M 97 (T 23) WHEN FIRED THROUGH A 1/4 IN. MILD STEEL
TARGET PLACED NORMAL TO THE LINE OF FIRE. FUZE PD T 71 R 4

THIS IS THE FIRST OF A SERIES OF
X-RAY PICTURES OF THE FUNCTIONING OF
A 20 MM. H.E.I. SHELL M 97 (T 23) WHEN
FIRED THROUGH A 1/4 IN. MILD STEEL
TARGET PLACED NORMAL TO THE LINE OF FIRE.
FUZE PD T 71 R 4



9 27 28 1944

HIGH SPEED X-RAY PICTURES OF THE FUNCTIONING OF 20 MM. H.E.I.
SHELL M 97 (T 23) WHEN FIRED THROUGH A 1/4 IN. MILD STEEL
TARGET PLACED NORMAL TO THE LINE OF FIRE. FUZE PD T 71 E 4



REF. #15155-3

FIGURE 17

9 JUNE 1945

HIGH SPEED X-RAY PICTURES OF THE FUNCTIONING
OF 20MM HE I SHELL MK I WHEN FIRED THROUGH
A $\frac{1}{8}$ IN MILD STEEL PLATE PLACED NORMAL TO THE
LINE OF FIRE

THE NOSE OF THE SHELL HAS PASSED THROUGH THE PLATE
THERE HAS BEEN NO SHIFT OF THE DETONATING PARTS OF
THE FUZE

THE SHELL HAS STARTED TO SWELL IN THE REGION OF THE
BOURRELET THE BOOSTER HAS NOT YET DETONATED

THE SHELL HAS SWELLED MORE THAN THE SHELL PICTURED
IN 6 THE MAXIMUM SWELLING IS STILL IN THE REGION OF
THE BOURRELET THE BOOSTER HAS DETONATED THE RING
OF PETALS ABOUT THE SHELL CAN BE SEEN

THE SHELL BODY HAS SWELLED TO ALMOST TWICE NORMAL
DIAMETER THE PETALS HAVE CONSTRAINED THE BOURRELET
REGION OF THE SHELL FROM SWELLING AS RAPIDLY AS THE
BODY OF THE SHELL THE BASE OF THE SHELL HAS SWELLED
VERY LITTLE

THE SHELL HAS RUPTURED THE BASE OF THE SHELL IS
STARTING TO MUSHROOM OUT THE CONSTRAINING EFFECT
OF THE PETALS IS EVIDENT

THE BASE OF THE SHELL HAS MUSHROOMED OUT EVEN FURTHER
THE NOSE AND SOME OF THE SHELL FRAGMENTS HAVE PASSED
OUT OF THE CONSTRAINING INFLUENCE OF THE PETALS

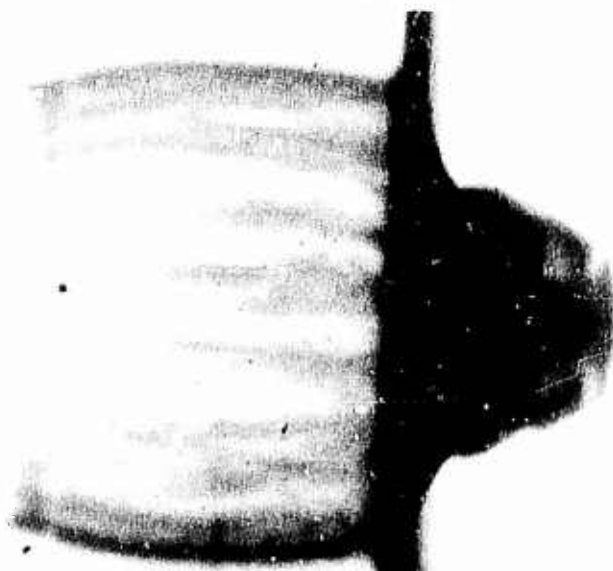
THE SHELL FRAGMENTS ARE ALMOST ALL COMPLETELY THRU
THE HOLE THE PETALS HAVE CURLED BACK TO FORM A
HOLE OF APPROXIMATELY 2 IN DIAMETER

THE PETALS HAVE CONTINUED TO CURL BACK TO
FORM A HOLE APPROXIMATELY 2 IN DIAMETER
THE SHELL FRAGMENTS ARE STILL
BEHIND THE PETALS IN THE HOLE

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PICTURE 18

High Speed X-Ray Pictures of the Functioning of 20 mm. H.E. Shell, MK-3
(Navy) When Fired Through a 1/8 in. Mild Steel Target Placed Normal to
Line of Fire



NEG. #15657-4

FIGURE 19

9 JUL 1945