ELECTROMAGNETIC PROXIMITY FUZE FOR MORTAR SHELL

Final report on contract N-02-MWP-A-54

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1.0 SUMMARY OF REPORT

This report gives data, drawings and descriptions of the VT-fuze for the 81 mm shell M43, as complete as has been possible up to the end of the development period.

Firstly, some theoretical and tactical aspects are considered. The exterior-ballistic data, the electrical and the terminal-ballistic data of the VT-fuzed shell are briefly described concluding with the preferred sensitivity setting of a VT-fuze for this projectile. Secondly, the VT-fuze model developed at the NDRE is described in detail, drawings are presented and pilot plant production is described. Further, a short chapter is devoted to the different test specifications applicable to this fuze, while a more extensive chapter deals with the actual proving ground test results. Lastly, in the conclusion, results of operational analysis are taken into account, concluding with some aspects on quantity production of this fuze model in Norway.

As will be known, work on this project started in late 1953, and became accelerated from May 1954 when the MWP contract was signed. The original final date of the project was stipulated to June 30th 1956, but was postponed until December 31st 1956. The personnel engaged in this program has comprised three or four graduated engineers during the whole period, and four technicians most of the time. In addition comes the group's share in the general special advisors from other branches within the NDFE.

2.0 THEORETICAL AND TACTICAL CONSIDERATIONS

This chapter commences with a comparison between PD-fuzed and VT-fuzed shells as to exterior ballistics. As a starting point, only the 81 mm mortar projectile M43 is dealt with, and the shape and weight of the VT-fuze is considered known. Later on, the different points of interest in the VT-fuze are briefly described, making it possible to obtain the theoretical data necessary for determining the best tactical applications of the projectiles, and for determination of the optimum sensitivity setting of this fuze.

2.1 Exterior-ballistic data for 81 mm shell M43

We will consider the firing tables for this projectile, in the first case equipped with super-quick impact fuze (PD-fuze), in the second case equipped with proximity-fuze (VT-fuze). When dealing with the VT-fuze, we will assume that the fuze will be able to replace the PD-fuze by just unscrewing the latter one, using the same booster cavity in the shell body. As a consequence of this fact, and our earlier experiments on sub-miniaturization, it would be necessary to have a considerably greater volume in the VT-fuze. With our existing technological means, it was thought necessary to use a cylindrical fuze with a total volume of about 175 cm^3. Due to various experiments on flight stability, we also found it necessary to increase the weight of the VT-fuze unit to 550 grams as compared with 250 grams for the PD-unit. In the photographs, figure 2.11, the fuzed projectiles in these two cases are shown.

2.11 PD-fuzed projectile

In FT 81 D-3[1] is given the firing table for the originally PD-fuzed M43 projectile. The total weight of the fuzed projectile is 6,87 lbs, or 3,12 kgs. As will be known, there are 7 different charges on this projectile, ranging from charge 0 (no charge increments) to charge 6 (6 charge increments). When using the trench mortar 3" Mk. 1A2, charges 5 and 6 are not supposed to be used, giving the weapon a useful firing range between 200 and 2300 metres. The firing table is shown graphically in figure 2.12, the solid lines indicating PD-fuzed projectile.

2.12 VT-fuzed projectile

Range and flight time data for the Norwegian model of VT-fuzed M43 have been collected from a total of approximately 50 rounds fired on different proving grounds. From these data, and the Otto-Lardillon's tables of flight, the best fitting drag coefficient has been calculated, giving

$$c = 4,6 \cdot 10^{-4} \ m^{-1}$$

As a comparison, the drag coefficient with PD-fuzed M43 projectiles lies between 1,5 and 2 $\cdot$ 10^{-4}, indicating that the heavier and far more clumsy shape of the VT-fuze does contribute very much to the frictional losses.

From this experimentally found drag coefficient, firing tables have been worked out, and are also shown graphically in figure 2.12. Naturally, these tables are not to be used in eventual realistic firings, as more data would have to be collected. However, for the following considerations and for our experimental firing purposes, the data are sufficiently accurate.

As will be seen from figure 2.12, the useful range possibilities of the projectile with VT-fuze have been decreased, giving from 500 to 1550 metres, compared with 200 to 2300 metres for the PD-fuzed one.

2.13 Flight stability and dispersion

Various firing tests have indicated that the stability during flight is approximately the same for the PD-fuzed and the VT-fuzed projectile. During the first seconds after firing, some instability will occur on both types, but the dispersions in length and width are still tolerable. The length dispersions are in accordance with the variations in initial velocity of the projectile, and obviously cannot be avoided except by more careful choice of charges and charge increments. This naturally is beyond the scope of this project. The width dispersions are about one half the length dispersions.

2.2 Electrical characteristics of the mortar shell VT-fuze

In principle, the VT-fuze consists of a Doppler-sensitive oscillator unit, an audio frequency amplifier feeding the thyratron firing tube, as well as a power unit.

2.21 The oscillator unit

The oscillator, Colpitts-coupled through the electrode capacities of the triode vacuum tube, has a working frequency of approximately 137 mc/s. The oscillator is inductively linked to the antenna, being an unsymmetrically fed dipole. One part of this dipole is the projectile body, while the other part is most of the fuze body, separated by a low-loss insulating ring of polyethylene. Low-frequency variations in the anode current of the oscillator tube, due to possible variations in the real part of the impedance of the dipole antenna, produce voltage variations across the oscillator plate resistor. These variations in antenna impedance occur when the antenna approaches any target, especially the ground. The antenna being short compared with the wavelength,

one should expect the radiation diagram of the antenna to be similar to that of a Hertzian dipole, giving zero in the direction of flight. This is correct for great distances from the antenna (more than 10 wavelengths), but at closer distances, the radiation diagram is considerably modified. As a consequence, for distances between antenna and ground of from 1/2 to 4 wavelengths, the zero in the radiation (or the reflection) diagram of the antenna will disappear, resulting in a reflected signal more or less independent of the angle between flight direction and ground normal.

In order to obtain a picture of the reflection conditions as a function of angle of impact at different heights above ground, special experiments had to be conducted. From a wooden tower, 10 metres high, a M43 projectile was hauled down by means of a small winch. The projectile was secured to an insulating "cradle", by means of which the angle ω between projectile axis and the horizontal plane could be adjusted. The projectile was equipped with a dummy fuze of the same dimensions as the ordinary VT-fuze, but containing only a battery-powered oscillator for 137 mc/s. As great difficulties were involved in telemetering the plate current of the oscillator without disturbing the radiation diagram of the projectile antenna, use was made of the fact that the self-impedance of the antenna varies along a spiral in the complex plane as the antenna is moving closer to the ground. Accordingly, we might measure the variation in the reactive component of the antenna impedance instead of the ohmic one, and this component may be observed by measuring the frequency modulation on the fuze frequency during descent. As we are only interested in the relative variations, this measurement is very easy to carry out. Figure 2.21 shows the recordings of relative frequency deviation during descent of the projectile, the angle between the latter and the horizontal plane being 60, 70, 80 and 90 degrees respectively. In figure 2.22 the data from fig. 2.21 have been reduced, and this figure shows relative reflection amplitude versus projectile height above ground at these same 4 angles of impact. As will be seen, the reflection amplitude at $\omega = 60°$ varies inversely proportional to the height, as will also be the case at $\omega = 0°$ (horizontal dipole). However, at $\omega = 90°$, the amplitude varies inversely proportional to the second power of the height, as may be readily shown to be the case

for a vertical dipole above ground. Finally, in <u>figure 2.23</u> are shown the calculated reflection amplitudes at discreet half-wave length distances n above ground as a function of angle of impact. These half-wavelength points are exactly the points where, due to the phase conditions in the oscillator and the succeeding ampli-fier, the firing of the thyratron will most probably appear.

Accordingly, from figure 2.23 it will be clear that the reflected signal is practically constant for angles of impact between 70 and 90 degrees and heights between 2 and 8 half-waves (2,2 - 8,8 metres). As will be shown later in this report, these conditions will be the most common ones, and this is most conven-ient for the purpose of determining the tactical firing conditions.

2.22 The characteristics of the Doppler signal amplifier

This is a relatively ordinary 1-tube amplifier around the tetrode DF68, working with fixed negative grid voltage. The tube is AC-heated, and amplification is approximately 60 from input (plate resistor 8 K ohm of the oscillator tube) to the output (1 M ohm grid resistor of the thyratron). The amplifier is blocked immediately after firing by applying negative voltage to the screen grid, and will not be active before the projectile has moved about 600 metres in its trajectory. The amplification is practically constant within the range of Doppler frequencies for this projec-tile (65 - 110 c/s). The output of the amplifier feeds the grid of a thyratron through a blocking capacitor. This thyratron has a DC bias of -7 volts, and the firing point being -3 volts, a peak amplitude of 4 volts from the amplifier is necessary for firing. The firing capacitor and the electric composition detonator are in the plate circuit of the thyratron. The combined sensitivity of the amplifier and thyratron circuit is specified in mV rms for firing and normal values for this amplifier are 20 to 40 mV rms. In case of electronic failures in oscillator or amplifier units, an impact contact provides discharge of firing capacitor through detonator.

2.23 The power supply

The supply of power to the oscillator, amplifier and firing arrangement is obtained primarily from a wind-driven

AC-generator, connected to a rectifier unit. During the development of the project, various types of power supply were considered, but this solution was found to be the simplest one from a constructional point of view, as well as giving an inherently very useful means of transport and bore safety. The electrical frequency from the generator versus the projectile velocity will be seen from figure 2.24. Here are shown the results of different firing and wind tunnel tests, and for later discussion, the observed points may be considered to lie between the two straight lines in figure 2.24. The H.T. output from the generator is voltage-regulated, and for generator frequencies greater than 2000 c/s the regulation is better than 1%. Below 2000 c/s. the voltage drops very rapidly. The accurate regulation characteristic is necessary to block out wobbulations in flight velocity, which would otherwise have resulted in voltage pulsations flowing straight through the filtering units and to the thyratron grid. Below 2000 c/s, i.e. during passage of the trajectory top in most rounds, the amplifier is blocked, and no wobbulations can pass. This is achieved by means of a capacitor in series with the AC heater voltage yielding a very sharply defined cut-off frequency due to the Richardson effect on cathode emission.

2.24 The safety devices

Arming of the fuze occurs normally after 2900 revolutions of the turbine, or 11600 electrical cycles of generator frequency. The arming is electro-mechanical, the short-circuit of the electric detonator is released and the detonator is coupled into the firing capacitor circuit. At the same time the detonator has reached a position where, in case of firing. it will be able to initiate the rest of the explosive train. Also at this same time, the screen voltage in the amplifier changes from negative to positive, activizing the amplifier half a second later. As has been mentioned above, at the top of the trajectory the amplifier is blocked if the generator frequency should drop below 2000 c/s and will not be unblocked until somewhere during the descent when the generator frequency has exceeded this value again.

2.3 Reflection characteristics of the ground

During different tactical situations, various types

of soil will be met during VT-fuze firing, and since the reflec-
tion coefficient of the soil varies, certain fluctuations in burst
heights are unavoidable. Knowledge of the reflection coefficients
of various ground types is therefore essential.

2.31 The measured reflection coefficients above varying ground

During the spring of 1956 tests were performed by lowering
a horizontally suspended dipole antenna, fed from a battery-powered
oscillator on 137 mc/s[2]. By measuring the variations in plate
current of the oscillator at discreet half-wave points above ground,
and comparing with reflections from a large brass cloth, the foll-
owing reflection coefficients were found:

Brass cloth	1,0
Sea water	0,86
Forest ground	0,64
Grass-covered ground	0,54
Rock	0,40
Gravel high-way	0,40
Dry sand	0,15

A reflection coefficient of 0,4 seems to be a suitable mean value.
By optimum setting of the fuze for a 0,4 ground, there will
obviously occur too low firings over sandy coil. However, sandy
soil without vegetation is very scarce in Norway, so we will
choose a reflection coefficient of appr. 0.4. or half the value of
sea water, as a suitable dimensioning value.

2.4 Terminal ballistic studies for the determination of optimum height
height of burst and relative effectiveness of air burst

The optimum   of burst of a mortar shell is greatly
dependent on the tactical case. Against standing unshielded men
on flat terrain a ground burst is usually preferable. On the
other hand it is quite obvious that air bursts are much more
effective than ground bursts against men in foxholes or open
trenches and against personnel shielded by rough terrain.

It is possible to calculate the fragment damage for
various tactical cases if the damage pattern and the number of
effective fragments per unit of target area as a function of the

distance from the burst are known.

Such data were not completely available for the 81 mm mortar shell, and though it was possible to make some approximate estimates of the optimum height and of the relative effectiveness, it was very desirable to carry out framentation trials on a military proving ground. Such trials with other types of ammunition (M-8 rocket, 260 and 500 lbs bombs) have been described earlier[3].

Three tactical cases were selected as of special interest: 1) targets simulating men prone on rolling terrain or in very shallow trenches (targets flush with the surface), 2) targets simulating men in medium deep trenches (targets 50 cm below the surface), 3) targets on snow-covered ground. In each case it was necessary to carry out the trials as static bursts without actually firing the shells. This was primarily due to the fact that no proximity fuzes were available at that time. As the remaining shell velocity is small compared with the mean initial fragment velocity (1:8), it is thought that the error which in this manner is introduced is of little significance.

2.41 Targets flush with the surface

The effect field consisted of horizontal 1.8×0.4 m boards, 1.3 cm thick, spaced 5 m apart in a square within a radius of 30 m. The total number of boards was 113. Seven projectiles were detonated at each of seven heights, $0 - 1 - 2 - 3.5 - 5 - 8 - 12$ m. Fragments which perforated the boards were counted and marked out after each burst. Every fragment which caused a visible mark on the rear side of the boards was taken as a perforation. In all trials the angle between the shell axis and the horizontal plane was 66°.

A perforation was supposed to represent a 50% probability of incapacitation. If more than one fragment perforated the same board, it was assumed that the casualties were independent of each other. With n perforations in the same board this assumption gives a probability of incapacitation

$$p = 1 - \frac{1}{2^n}$$

These assumptions are primarily of significance for the absolute fragment damage. In this connection we are only interested in the relative damage, and deviations from these assumptions will therefore be of minor importance.

It was necessary to make an assumption with regard to the damage caused by air blast from contact bursts. According to data given by Granström[4] the shock wave at a distance of 1 m from a detonating charge of this size will have a peak pressure of 6 atm which is the limit of serious injury to men[5]. A shell detonating within a distance of 1 m from a board will therefore cause incapacitation even if the board is hit by no perforating fragments. A correction for this effect was made both for contact bursts and for bursts at a height of 1 m.

All the trials were performed with the shell situated exactly over the central board. At the lower heights the position of the shell relative to the nearest board will be significant and a correction for this effect was made for the heights 0, 1 and 2 m.

The relative damage obtained by these trials is tabulated below:

Table 2.41

Height, m :	0	1	2	3.5	5	8	12
Relative damage:	1.2	3.0	2.9	4.4	2.9	1.9	1.4

The results are also given in figure 2.41. This curve is primarily drawn on the basis of table 2.41, but some consideration is also given to the number of fragments hitting the boards without perforation and to a theoretical calculation of the relative damage.

The data used for this calculation were taken from a table giving the number of effective fragments per square foot at various distances from the burst[5]. An effective fragment was defined as a fragment with at least 8 kgm of kinetic energy, and it was supposed that such a fragment would cause incapacitation of a man. The result of this calculation is given in figure 2.42.

It will be observed that there exists a significant difference, not only between the absolute values, but also between

the shape of the two curves of figure 2.41 and 2.42. The former
may be due to the different definition of incapacitation. The
latter is thought to be related to the fact that the data used for
the theoretical calculation are valid only for random orientation
of the projectile axis.

If it is supposed that a random orientation is equivalent
to a projectile angle of fall of $45°$, and further that the frag-
ment density has a maximum near a plane normal to the projectile
axis, it seems reasonable that a projectile with an angle of fall
of $66°$ will cause a smaller fragment damage than one with random
orientation and that the difference will increase with height of
burst. This explanation is supported by the experimental results
showing a considerably greater fragment damage behind the shell
than in front of it.

According to figure 2.41 the optimum height of burst in
this tactical case is 3.5 m giving an advantage ratio of about 3.6
compared with contact burst.

Several factors, however, which were not investigated,
will influence these figures.

The shell velocity will give the fragments an increased
velocity in the direction of the shell axis. With $66°$ angle of
fall only the vertical component of the increase needs consider-
ation. The effect of this increase is to concentrate the fragments
giving a greater optimum height and a greater advantage ratio.
The magnitude of this effect is thought to be small, but firing
trials will have to be carried out in order to give a quantitative
estimate.

Shells with impact fuzes will penetrate a distance into
the ground before detonating, thus giving a smaller fragment damage
than the shells bursting in contact with the ground in these trials.
As the impact fuze for 81 mm mortar shells is a superquick one,
the distance penetrated before detonation occurs is usually very
small. The fragment damage, however, decreases very rapidly with
the height of burst at very low heights and a small penetration
may therefore still be of significance. Firing trials would also
give valuable information with regard to this effect.

The angle of fall of the shell seems to be rather important, a smaller angle favouring a greater height of burst.

A greater distance between the targets will favour a greater height of burst.

Targets at a greater distance from the burst than 20 m will increase the optimum height of burst and the advantage ratio relative to contact burst.

2.42 Targets 50 cm below the surface

Some assumptions, based on wartime work on this problem of VT-fuze against men in trenches, are summarized. The type of cover is here defined as giving protection against all fragments coming down at angles to the horizontal less than an angle Θ. It is believed that the following factors do not affect the expected number of casualties per shell: 1) the average number of men in each trench, 2) total number of trenches and 3) for air bursts the area of each trench, except insofar as this affects the angle of Θ defined above.

Other considerations on types of shielding[5] conclude that the shielding labeled "10° foxhole" is believed to be that most commonly encountered. The term "10° foxhole" is defined as a foxhole in which an occupant will, on the average, be unharmed by fragments with an angle of fall less than 10 degrees. Greater shielding than "30° foxhole" is given no consideration.

For the firing trials referred to earlier [3] boards 2 x 6 feet, 12 inches below the surface, spaced 15 feet apart, were used as targets. This shielding was described as "shallow trenches". With 260 lbs and 500 lbs bombs an advantage ratio of about 20 was found at an optimum height of 15 m. In the same test it was found that if the targets are flush with the surface, an advantage ratio of 5 is observed. In the same report reference is given to British trials of effectiveness of airburst bombs against shielded targets. They differed from the American trials in that the targets were designed to represent men in deep foxholes as well as in shallow foxholes, they were spaced 30 feet apart, were smaller, and the effect of blast for the surface burst was included in the evaluation.

The advantage ratios - raised wire.

Height	Deep foxhole	Shallow foxhole
10 feet	4.0	3.7
25 "	3.7	5.3

In our fragmentation trials we used the same boards as earlier (1.8 x 0.4 m) and the same target arrangement. The boards were placed 50 cm below the surface. Thus the protection obtained was 51° against fragments perpendicular to the longest side and 76° against fragments parallel to the longest side. According to wartime investigations this shielding would be described as "shallow trenches". We find it, however, more correct to describe it as "medium deep trenches".

Ten projectiles were detonated at each of five heights. 2-4-6-8-12 m. The angle between the shell axis and the horizontal plane was 66°. Five projectiles at each height were detonated with the shell axis in a direction parallel to the longest side of the boards and five perpendicular to this direction. Of each group of five projectiles one was placed exactly over the central board, the other four 2.4 m in each direction from it, this arrangement roughly corresponding to random distribution.

The same assumptions with regard to fragment damage were made as previously. In order to obtain a comparison with contact burst, several shells were detonated at different distances from the border of the trench. No fragment damage to the board was observed even if the shell detonated at a very close distance of 15 cm from the longest side of the trench. On the short side one perforating fragment was obtained in two of four trials at a distance of 40 cm and none at greater distances. It was concluded that fragment injury would be of minor importance compared with blast injury.

An exact knowledge of the limiting distance for blast injury was therefore highly desirable. Fortunately the blast effect decreases very rapidly with the distance from the burst so that a fairly good estimate of the limiting distance may be made even if exact measurements of the blast are lacking.

Clemedson in his study on air blast injuries[6] states that the direct cause of death in blast injury is a respiratory and circulatory failure, being dependent both on maximum pressure and on impulse. As these quantities are highly correlated it is usually sufficient to consider the maximum pressure.

The measurements were made by recording on a counter-cronograph the time of arrival of the shock wave at two pressure-sensitive gauges spearoted by an accurately measured distance. Knowing the velocity of the blast wave and of sound, v and c respectively, and the ratio of the specific heats. γ , the ratio between maximum and atmospheric pressure is calculated from the theoretically established Rankine - Hugoniot equation:

$$p/po = \frac{2}{\gamma + 1} \; (\frac{v^2}{c^2} - 1)$$

The results showed that when the charge burst at a distance of 20 cm from the border, the pressure at the bottom of the trench rose to about 6 atm. Consequently the limiting distance of incapacitation of men was taken as 20 cm on the longest side and as 40 cm on the short side (in order to take some fragment injury into account). This gives a vulnerable area of 2.08 m^2 and a probability of causing incapacitation by ground burst of 0.083.

The relative fragment damage obtained by the burst trials is tabulated below:

Table 2.42

Height. m	:	2	4	6	8	12
Relative damage:		0.56	0.35	0.69	0.42	0.25

As the fragment perforations in these trials were very scarce, the reliability of the results is questionable. The results obtained from the trials with the targets flush with the surface were therefore recalculated in order to give an estimate of the fragment damage with this type of cover.

Both estimates are given in figure 2.43. A reasonable conformity seems to exist and it may be deduced that at an optimum height of 5.5 m the advantage ratio is 7.7.

2.43 Targets on snow-covered ground

The effect of a mortar shell with impact fuze on snow-covered ground is usually very poor. Only when the snow is very hard will the fuze function on the surface. Most frequently the fuze does not function until the projectile reaches firm ground. Under extreme circumstances frequent non-functioning of the fuze may occur. The chief reason for the reduced effect is however the retardation of the fragments passing the snow.

No investigation of shell fragmentation on snow-covered ground is known. Neither has it been possible for us to make such trials in the time available. The comparison of impact fuze and proximity fuze in this important tactical case has therefore to be based on statements from officers experienced in fragment damage from real or simulated combat. All the officers interrogated agreed that the reduction of fragment damage was very dependent on snow conditions, but very frequently the reduction was so great that the advantage of mortar was very questionable.

Under average snow conditions by which is meant 60 - 70 cm snow of medium consistency, a reduction of fragment damage by a factor of 5 to 10 compared with burst on bare ground was estimated by those presumably most conversant with the subject. The reduction of fragment damage compared with air burst may often be much greater. It is very difficult to give an exact figure for the advantage factor in the various refractions which may occur, but a value of twenty or even more does not appear unreasonable.

2.5 Conclusion, preferred tactical application of this weapon

By combining the results from 2.1 (firing tables), 2.2 (electrical fuze data), 2.3 (ground characteristics) and 2.4 (terminal ballistics), we may be able to find a reasonable compromise and determine a suitable mean setting of the fuze.

2.51 Definition of fuze setting

With "fuze setting" we will define the sensitivity of the complete fuze, measured in a standard test box by inducing a controlled disturbance until the fuze fires. In practice, this

is done by mounting the fuze base into a cubical aluminum box,
15 cm each way, and exciting the turbine with an external air
stream. (A dummy load, equal to the radiation impedance in free
space) is connected across the antenna gap (the polythene insulating
ring). A tuned circuit, tuned to the fuze frequency, is coupled
very loosely to the antenna gap, and the losses in this circuit
are made to pulsate by means of a germanium rectifier, excited
with 100 cps from an audio generator. The coupling between this
circuit and the fuze is variable, being calibrated according to
the results from about 30 successful firings. With this system
working, a sensitive fuze will need a very weak coupling until the
fuze triggers, while a less sensitive fuze will need a closer coup-
ling. Triggering or firing is observed by the extinguishing of a
neon lamp connected between the thryatron anode and ground (i.e.
across the antenna gap by means of r.f. chokes). Figure 2.51 shows
a photograph of this standard box.

2.52 Choice of preferred height of burst above average terrain

According to the terminal-ballistic tests and assumptions,
we may conclude that a nominal height of 4 half-waves (4,4 metres)
above ground with a reflection coefficient of 0,4 will be a
suitable starting. As tests above shallow trenches have indicated,
bursts about 50% higher will be suitable. This will probably be
realized, as trenches will most likely be dug in grass-covered
ground or forest terrain with reflection coefficient around 0,6.
As will already be known, with a given fuze, the burst height varies
proportional to the fuze setting, and also proportional to the
reflection coefficient. Of course, there are several factors
tending to increase the dispersion in height, as for instance
differences in obtained fuze settings (1:1,5), variations in angle
of impact at constant angle of firing ($\pm 2^{\circ}$), variations in angle
of impact due to roughness in the terrain. In addition, the
variations of reflection coefficients occur, so a certain range
of burst heights has to be specified. To make a suitable choice,
we will specify burst heights of between 3 and 6 half-wavelengths
above a ground of reflection coefficient K = 0,4. As has been
evident from practical tests and firings, these data will be
obtained by a fuze sensitivity lying between 3 and 4,5 relative

units in the standard test box. We will determine the burst heights for these settings graphically in the next chapter.

2.53 Burst heights from firing tables and the sensitivity pattern

From the detailed firing tables we may find the angle of impact connected with each combination of elevation and charge number. Further, from figure 2.23 we know the reflection amplitude in different heights above ground versus angle of impact. The rest of the data needed to determine the burst heights are the fuze setting R, the reflection coefficient K, specified by the product K.R, and some sort of connection between the relative amplitudes of figure 2.23 and the relative setting. From firing tests, we have observed that at an angle of impact of 72°, firing at charge 2 across sea water with K = 0.86 and a mean setting of R = 3.0 (K.R = 2.58) that the resulting mean value of burst height was 6 metres or 5.5 half-waves. Accordingly, in figure 2.52 the data from figure 2.23 are redrawn, but in addition, a new scale for K.R has superseded the old, relative scale from figure 2.23. We will choose a certain range of impact angles, sufficiently large to permit suitable range overlap for different charges, and for this weapon, the best range for the impact angle ω seems to lie between 65° and 74°.

Concluding then from figure 2.52, we find, for K = 0.4 and R lying between 3 and 4.5 burst heights of between 3 and 6 half-wavelengths. Furthermore, for K between 0.2 and 0.6 and R between 3 and 4.5 (K.R between 0.6 and 2.7) and no further restrictions or firing table, a possibility of dispersion in height above ground between 1 and 9 halfwaves exists.

Finally, in figure 2.53 is shown the firing tables with the restrictions mentioned above. Rounds fired with charge 0 and 1 have to be avoided, as the impact velocity in these cases may at times be lower than the limit according to figure 2.24 insuring an active amplifier. In figure 2.53, the "isoangles", joining firing points with constant angle of impact have been marked, and on these lines are also given burst heights with fuze setting R = 3.75 and based on average ground with K = 0.4. The firing curve for charge number 2 has been extrapolated beyond the

limiting impact angle of 74°. This has been done chiefly to widen the useful range of the weapon, and may be justified across all types of terrain except dry, sandy ground (deserts).

3.0 DETAILED DESCRIPTION OF THE NODE FUZE

Detailed descriptions and data for the NODE fuze will be given in the following. The chapter is subdivided according to the different functions of the main sub-assemblies. In the description, reference is made to the detailed drawings, all of which are enclosed in this report. Before going into details, there are a few points regarding the principles of drawings which need to be mentioned.

Firstly, the drawings are in principle made by means of the European standard drawing projection. This involves that for instance the side projection of a component will be placed on the opposite side of the top projection, compared to the American projection type. Secondly, diametrical tolerances are given in the ISA-system[7], consisting of one letter and one figure for each tolerance specification. The large letters indicate inner diametric dimensions (bore base), while the small letters indicate outer diameters (shaft base). The figure indicates the type of tolerance, whether one-sided ($\overset{+}{0}$, $\underset{-}{0}$), zero-sided ($\overset{+}{0}$, $\underset{-}{0}$) or double-sided ($\pm$). The tolerance figure is basically a relative measure. Thirdly, in order to keep the number of different drawings within a certain limit, photographs are also used as supplements in the following descriptions.

In drawing 84T1-1 is shown the complete fuze assembly. Detailed descriptions of the sub-units are given below. The different main parts of the fuze will now be considered. From the front end we have the power unit, the low-speed arming device, the audio frequency unit, the radio frequency unit, and the fuze base with the electric-mechanical-pyrotechnical arming system. Finally, we shall take a look at the assembly of the complete fuze as an integrated unit. Not to make this description too lengthy, we will only concentrate upon the completed product, and very little will be mentioned about the different, often very cumbersome, preliminary stages.

3.1   The power unit

The total power drain to the tubes and circuits is roughly 2 watts. This power has to be delivered to the circuits partly as alternating current (320 mA at 1,25 V rms). partly as direct current (10 mA at 125 VDC). To facilitate the construction, we have chosen to feed the fuze from a wind-driven turbine-generator. The generator feeds AC to the audio unit. where the high-voltage part of the supply is regulated, rectified and filtered. The turbine-generator consists of the following main parts: In front, inside a turbine housing, is the nylon 8-bladed turbine, mounted on the rotor shaft, rotating in ball bearings. On this same rotor shaft is the Alnico V ring magnet, which acts as a rotor. Around the rotor is the stator: silicon iron laminations with 2 wave-wound coils, embedded into the generator housing by means of an epoxy resin. To the stator laminations is connected a magnetic shunt ring, acting as voltage regulator. The terminals from the two winding coils, two from the high-voltage one and three from the low-voltage center-fed coil, are brought out through the embedment by means of a nylon contact assembly, facilitating an easy means for further solder connection to the audio frequency part of the fuze. To the generator housing is mounted the bearing fixture, containing the back ball bearing for the rotor and a gear mounting plate with reduction gears to an arming shaft.

Figure 3.11 shows the complete generator. The bearing fixture is seen to the left, with the splined tap to the arming shaft protruding backwards. This bearing fixture fits very tightly into the generator housing to ensure the necessary small tolerances between the stator and the rotor.

Having given this short review of the main parts, the different electrical and magnetic data for this unit will now be considered.

3.11   Specifications for the turbine-generator assembly

As has been shown earlier in figure 2.24 maximum output frequency of the generator will never exceed 5000 c/s, and with 8 poles this gives a maximum rotational speed of 75000 rpm. However, the rotational speed and the frequency vary approximately

linearly with the projectile velocity, and basically, the output
voltage from this type of generator with a permanent magnet rotor
will also be proportional to the speed. To ensure proper function-
ing of the electronic circuits of the fuze however, the supply
voltage has to be stabilized to a high extent. Our specifications
for the high voltage from the generator, measured after rectific-
ation and filtering for the plate supply of the oscillator tube is
98 V ± 1.5% for a calibration frequency of 2000 c/s. This tole-
rance indicates the permitted deviation between all generators in
one production batch. However, for one and the same generator,
the output voltage (converted to DC) will lie within ± 0.5% for
any practical frequency between 2000 and 5000 c/s. These tolerances
will not automatically be realized for the low-tension terminals
but oscillator and amplifier circuitry has been constructed non-
critical in regard to the filament voltages. The reason for these
very accurate specifications for the regulation is as follows.
The natural frequency of wobbulation during flight for this pro-
jectile is approximately 5 to 10 c/s. With a regulation character-
istic, i.e. a generator voltage vs. frequency, not nearly horizontal
a flight wobbulation would be converted into a voltage wobbulation
through the turbine and the generator. This voltage wobbulation
will pass relatively non-reduced through the rectifier, filtering
and into the electrodes of the tubes, giving rise to noise voltages
within a frequency band not very far from amplifier pass band, and
likely to fire the thyratron. A complete telemetering program has
given data as to the actual value of the frequency wobbulations, and
has made it possible to specify the generator characteristic nec-
essary to avoid these noise voltages with large safety factors.

Figure 3.12 shows the generator voltages for a typical
generator, and shown is also the tolerance limits during production.

The generator regulation characteristic is obtained
partly by means of a magnetic shunt ring, increasing the leakage
flux linkages at higher speeds, and partly by an R-C series
resonant circuit across the HT circuit. This resonance effect
boosts the output voltage at 2000 c/s with a very low Q, so the
characteristic may be very nearly flat within the specified freq-
uency range.

As to the aero-dynamic data of the turbine-generator, the maximum starting air velocity measured in a wind tunnel is specified as 25 m/s. The maximum stop velocity is 15 m/s. The maximum generator speed will in practice never exceed 75000 rpm, but running tests up to 90000 rpm have been conducted to ensure against mechanical breakage of the turbine.

In addition to satisfying these specifications, the generator assembly, in common with all sub-units of this fuze, is shock-tested for 8000 g's, according to the specifications in chapter 4.0.

3.12 Detailed constructional drawings of power unit

Drawings nos. 84T1-101 - 84T1-114 inclusive show the turbine-generator in detail. The parts for the arming shaft reduction gearing are for practical reasons described in a later chapter. The stator parts are the generator housing, with the back plate or bearing fixture, the laminations with a paper spacer and a magnetic shunt ring, as well as the winding coils and a contact assembly, embedded in Araldite D. Further, two roller bearings and a snap ring complete the stator. Dwg. 84T1-106 shows how the machining of the potted stator is done, before insertion of the snap ring and the large (3/16") roller bearing. The rotor parts are the rotor shaft, centered into the ring magnet, by means of Araldite resin, the turbine nut and the turbine. After completion of the turbine-generator unit, this section is tested and adjusted, connected electrically to the amplifier unit, and mechanically through the gear trains to the arming shaft, after which the power unit is connected to the A.F. unit mechanically by the turbine housing. This housing acts partially as a retaining ring, partly as a lead-in and lead-out for the air-stream to the turbine, and partly also as a means for stabilizing the fuze during flight.

In connection with the detailed drawings of the power unit, notice must be given to the very close tolerances specified. This is necessary firstly to ensure a good dynamic balance during high rotational velocities, and secondly because of the very small air gap, 0,1 mm, which is necessary between the rotor and the stator. The latter is the reason for our choice of Alnico V as

material for the ring magnet. This material has a fairly high
energy product for an isotropic material, but relatively low
coercitive force. Consequently, a larger air gap would have too
large a demagnetizing effect on the magnet, and would give a
working point on the hysteresis loop too far away from the point of
maximum energy product. However, Alnico V, or Philips Ticonal, is
the only magnet material produced in Norway at present, although
we are fully aware that for instance Alnico IV might permit a
larger air gap and looser tolerances.

3.13 Description of pilot production

The necessary mechanical parts are made according to
the drawings shown. During the last stages of this off-line pro-
duction, the in-line production is started by winding the genera-
tor coils. The HT coil consists of 1000 turns of 0.07 mm dia.
Duroflex-covered wire, wound in a circular fashion. The LT
winding consists of 2 x 8 turns 0,4 mm dia. Duroflex-covered
wire. Winding mandrel diameter for these two coils are 42 and
40,5 mm respectively.. To the wire ends from the HT winding is
connected special Litz wire, made of 8 strands of 0.07 mm
Duroflex wire, the Litz wire being interwound with the terminal
wire to increase mechanical strength, but, as will be noticed,
only the original single wire conducts current. The inner end of
the Litz wire is insulated by means of bakelite laquer to prevent
the different strand ends from damaging the coil. The two Litz
wire output leads are secured to the coil with a small piece of
PVC adhesive tape, and the whole coil with terminal points is
given an outer insulation consisting of one layer of silk woven
tape. The same process applies to the LT winding, but here the
two wire ends as well as the double center lead are strong enough
to act as terminals. After these processes, the windings have
ring shape. The two coils are shown in figure 3.13 amongst the
other generator components.

Now the coils have to be pre-shaped according to their
final wave-shape in the stator. By means of a special shaping
jig this is carried out, and the process of mounting the coils
into the 9 stator laminations is commenced. The HT winding is
mounted with the terminals extruding on top of one of the stator

poles. In the next operation, the LT winding is mounted, with
its terminals on the third pole counted in clock-wise direction
from the HT terminals. The coil waves are bent outwards from the
stator center, to facilitate later assembly of the magnetic shunt
ring, and are firmly pressed to touch the outer plane surfaces of
the lamination packet.

At this stage, the completed stator is pressed into the
stator housing, as shown in figure 3.14. The orientation between
the stator and the housing is apparent from this photograph. The
nylon contact assembly is placed into the side slot of the housing,
and the five terminating leads from the windings are put one into
each slot in the contact assembly. The terminating leads have,
before this operation, been stripped for insulation by a special
chemical laquer solvent. To facilitate the potting process, the
radial holes in the contact assembly are filled with drops of
Araldite D after the terminals have been brought in. Having laid
in the paper spacer ring and the magnetic shunt ring, which are
pressed together with the stator laminations by a special jig
assembly, the unit is ready for the moulding operation. Araldite
D with 10% hardener 951 is used, and pouring as well as hardening
is carried out at room temperature. After hardening of the resin
(2 days) there is one step of offline production.

The completed stator is machined according to dwg.
84T1-106, to ensure proper concentric rotor opening and ball
bearing surfaces. The groove for a roller bearing snap ring is
also machined in this operation.

In-line again. roller bearings both in the stator
housing and in the bearing fixture are pressed into position.
the "large" bearing after the snap ring has occupied its groove.
Figure 3.15 shows this stage. Parallel to these production stages
of the stator, the rotor assembly is carried out. The ring magnets
are moulded accurately concentric to the rotor shaft by using
Araldite 101 hot-setting adhesive. This is hardened for 3 hours
at 150° C. and during this operation. shaft and magnet are held se-
curely in a special jig. The worm end of the shaft. is protected
by coating with 2 layers of silicone rubber, hot prepared at 150°C.
The rotor, after assembly to shaft, and having been cleaned by

machining off superfluous Araldite. is magnetized with 8 poles in a magnetizing jig. During this shock-magnetizing process. a capacitor discharge (1500 volts from 150 MF) is led through 8 series-parallel coils on the 8 magnetizing poles. and a remanent induction of 8500 Gauss is obtained. This is the highest obtainable value from 8 poles in a ring-shaped rotor with these dimensions made from cast Alnico V in the isotropic state. A certain demagnetizing effect will be present when the rotor is taken into the air. This magnetized rotor with rotor shaft is tested by rotating it past a search coil at 1500 rpm. induced voltage in the coil being observed with a vacuum tube voltmeter. The tested rotor assembly is mounted into the stator ball bearing. and the turbine and the turbine nut are threaded on and secured. Finally. the bearing fixture with the gear mounting plate and gears is pressed into the generator housing and onto the generator shaft. and the unit is ready for final test and calibration.

In this state. the generator will yield too high voltages measured on a dummy load. However. with the turbine driven at 30 000 rpm (by an air-blower). small and increasing DC pulses are passed through the HT-winding. causing a demagnetizing effect on the rotor. The pulse amplitude is slowly increased until finally a voltmeter across the LT voltage shows correct value. After this operation, the generator is stable as regards short-circuiting of the output terminals. as well as in respect to shock tests; no further demagnetization may be obtained by either means, and ageing will also show no effect. The generator is now run with varying speed. and the HT regulation characteristic (voltage vs. frequency) is displayed directly onto the face of an oscilloscope. In this process. the voltage axis is magnified to give an exact picture of the regulation curve above 2000 c/s (the "flat" part of the characteristic). and generators outside the tolerance limits for the flatness are discharged. Having passed this test, the generator is shock-tested according to chapter 4.0, and is completed as a sub-assembly. To give a practical pilot-plant result, from one batch of 50 turbine-generators. all passed the tests and were used either during firing or for laboratory tests.

3.14 Discussion on quantity-production possibilities of generator

The pilot production of turbine-generators has at our laboratories been carried out by only one person at a time on the in-line processes and between 1 and 4 workers on off-line production. To be able to discuss series- or mass-production data for this unit, we give a rough estimate of our pilot production prices (series of 50 generators). This estimate is given in table 3.11.

Table 3.11

Pilot-prices (incl. overheads)

Mechanical parts- cost of material	N.kr.	25.-
" " cost of labour	"	70.-
In-line production - labour	"	30.-
Testing and control	"	15.-
Total pilot price	N.kr.	140.-

It is estimated during series-production that the total price of the power unit may drop to approximately N.kr. 85.-. provided series of minimum 2000 units are produced and complete tooling equipment for all critical operations is available. In addition the two larger parts. turbine housing and generator housing, will have to be brass pressure-moulded with a slight final machining. instead of being machined down from solid material as is done in pilot production.

As to series-production facilities. already during pilot production some components have been ordered from civilian firms outside our Establishment, and it is assumed that the parts may all be obtained from different sub-contractors. By introducing a different type of material for the ring magnet, looser tolerances might perhaps even reduce the price by N.kr. 15.-. and roller bearings might possibly be omitted and be replaced by Oilite bearings.

3.2 The reduction-gearing assembly

This group of components consists of all rotating parts between the generator rotor shaft and the arming rotor in the base

of the fuze. Dwg. 84T1-2 shows a simplified drawing of the
assembly. A generator worm engages a worm gear in the gear
mounting plate. situated in the generator bearing fixture. This
worm gear is combined with another worm. again engaged into a gear
connected by splines to an arming shaft, the latter leading excen-
trically through the electronic part of the fuze into the fuze
base. Here the arming shaft is splined into a third worm,
engaging the arming rotor in the explosive train. In figure 3.21
is shown a picture of the gearing assembly.

3.21 Specifications for the gear assembly

The main function of this assembly being to ensure a
safe delay after firing. a tentative specification was set up.
according to which arming should occur after minimum 2500 revo-
lutions of the turbine. According to the specifications for the
generator, and the data in figure 2.24. the air travel of the
projectile is approximately 0.09 m for each revolution of the tur-
bine, so this safety specification would give a safe distance from
firing place of 225 metres. The purpose of the mechanism is to
turn the arming rotor 180 degrees from the safe to the armed
position, so the gear assembly would have to reduce the turbine
rpm by a factor of at least 5000. A minimum of three worms would
be necessary to perform this operation, and our final solution
gives a reduction ratio of 12 in the first worm. 22 in the second
and 22 in the third counted from the generator. The resulting
ratio of 1:5808 is a little higher than originally specified. and
gives a safe distance of approximately 260 metres along the
trajectory.

During the development work, it was found that the
whole gear assembly would preferably have to be made of nylon. to
avoid noise voltages introduced into the oscillator. And further.
the arming shaft, having to pass closely through both amplifier
and the oscillator part of the fuze, needed to be made of a material
rigid enough to stand the shock tests and at the same time only
causing very small losses at fuze frequency. around 140 Mc/s. Our
experiments brought us to the choice of a super-polyethylene.
Details of the reduction-gearing assembly are shown in dwgs.
84T1-201 - 206.

3.22 Pilot plant production

The reduction-gears. etc are practically entirely cast in nylon or super-polyethylene. Consequently, with the moulds finished, the moulding and mounting operations are very easy and rapid, so an estimated working time per unit is one-half hour, including control. No comments on this production are necessary, other than to point out that the work carried out to bring these moulds to a suitable state, taking care both of shrinkage during moulding and growth during conditioning processes, was at times very cumbersome and required re-construction of moulds and moulding meachinery.

3.23 Series production of the reduction-gearing assembly

Since this production involves only ordinary plastic manufacturing processes. no difficulties should be excountered in series production. Estimated unit price is N.kr. 5m. Any manufacturer in the plastic industry might be a sub-contractor for this unit.

3.3 The amplifier unit

The A.F. part of the amplifier unit will amplify the accepted Doppler voltage from the oscillator plate. suppress noise components from the plate and filament supply voltages. feed a thyratron and bring this tube to fire at sufficiently large Doppler input signals. This will cause a firing capacitor to discharge through the thyratron and also through an electric detonator, initiating the explosive train. Further, the amplifier unit is fed with alternating voltages from the generator unit. The high tension voltage is rectified filtered, and fed to the amplifier, the oscillator and the thyratron plates. The amplifier unit shall be inactive as a safety guard against jamming during part of the flight when generator frequency drops below 40 c/s and also for overcoming modulation difficulties, as mentioned earlier. Besides, like all sub-units of the fuze, the amplifier unit will be shock-tested at 8000 g, and will pass severe climatic tests.

3.31 Description and characteristics of unit

Drawing 84T1-308 shows the circuit diagram of the amplifier unit. Starting from the rectifier OB, a voltage-doubler, consisting of series-connected germanium diodes OA 91 works into the two doubler capacitors of 0.25 MF. A further capacitor of 0,5 MF completes the charging capacitor assembly. The rectifier delivers bias to the thyratron and to the amplifier tube through the double drop-resistor of R_{17} and R_{18} in series. To stabilize the bias against variations in DC current through the oscillator tube (the only real current-consuming part of the circuit) a bleeder resistor, R_{11} draws a current of 4.25 mA. As has been mentioned in connection with the generator, a series-resonant circuit, consisting of C_8 and R_{16}. as well as the reactance of the generator as seen from the HT terminals. takes care of the diminutive voltage variations from the magnetic shunt-regulated generator. The DC output from the voltage-doubler enters three different paths. One goes, through the R_{20} - C_{14} decoupling circuit to the oscillator plate feed. one directly to the amplifier plate feed. Through a third path the firing capacitor C_{12} is charged through the thyratron plate resistor of R_{10} and through the electric detonator (giving rise to a peak current of 0.12 mA during charge). This path also feeds the amplifier screen grid.

The circuit around the amplifying tube is degenerative above appr. 150 c/s. slightly regenerative near the peak frequency of 100 c/s. and with practically no feed-back at lower frequencies. The amplification vs. frequency is almost flat in the region 65 - 110 c/s, and drops off at higher and lower frequencies. This frequency characteristic is obtained by feed-back around the tube. and in addition by low-pass filters in the input and the output of the amplifier. and by the coupling capacitors. Firing point for the thyratron is -3 volts. The normal bias on the thyratron grid however. is -5 volts. so an output signal from the amplifier of 4 volts peak-to-peak is necessary for firing the thyratron. The detonator. which also acts as a switch for the screen grid voltage. is connected into the circuit after the arming time of 2 - 4 secs has elapsed. Before this time. however screen grid is at -5 volts. and the amplifying tube is blocked.

The unit is also equipped with an impact contact. This is normally open-circuited, and is situated between the thyratron plate and ground, in those cases where failures in oscillator or amplifier circuitry occur, this contact initiates the firing train at impact, However this happens provided no failures in generator or rectifier unit occur. It is estimated that approximately 80% of the possible VT-duds will thereby be converted into PD-rounds.

The filament circuit of the amplifier has a special mission. At low generator frequencies, the series capacitor acts as a high impedance, reducing the filament current. As the frequency increases filament voltage will increase, as will be clear from figure 3.12 and at a voltage of approximately 0.7 rms the tube will start to conduct. Due to the Richardson law for cathode emission, according to which emission current varies proportional to a high power of the filament current, a very well defined opening of the amplifier will result. In the fuze circuit, the amplifier will be inactive at frequencies below 2000 c/s and fully active with constant amplification above 2300 c/s. Besides yielding a safety against noise from wobbulation during the steep part of the HT regulation characteristic this circuitry also desensitizes the fuze during part of its flight around the top of the trajectory, i.e. where projectile speed drops below 65 m/s. No jamming signals are able to fire the fuze during this time.

The amplifier and thyratron unit as a whole has a sensitivity which is specified as the actual mV rms from the oscillator plate necessary for firing of the thyratron. The mV for firing usually lies between 20 and 30.

From figure 3.31 will be seen the frequency characteristic of a typical amplifier shown as mV for firing at different signal frequencies, As will be noticed, a practically constant amplification is obtained inside the pass band of 65 to 110 c/s. In figure 3.32 is likewise shown the mV for firing at 100 c/s signal frequency, versus generator frequency. The passivizing of the amplifier at frequencies below 2000 c/s is apparent.

In figure 3.33 is shown the complete parts list for the electronic components of the amplifier. As to the tolerances for

the components, conclusive tests have been carried out to determine the influence of varying the different components upon the mV for firing in a laboratory assembly[9]. Most components are uncritical, i.e. resistors and capacitors with tolerances of ± 10% or more are acceptable, but the tubes are naturally critical, as are also the thyratron grid leak of 1 M ohm and the resistor in the bias circuit for the thyratron. Sensitivity varies linearly with each of these resistors. The resistors, therefore, are specified at ± 5%, and may in practice be assumed evenly spread across this range. As to the different tubes, quantity-testing has shown that sensitivity variation of the amplifier tubes may be assumed evenly dispersed between ± 8%, while different thyratron tubes may give rise to an evenly spread variation of ± 5%. Accordingly, the sensitivity variation in a production batch will very nearly follow a Gaussian law, with standard deviation ± 6%. 95 out of 100 amplifiers showing sensitivities within ± 13% and no amplifier outside the ± 23 % limit.

3.32 Drawings and photographs of the AF unit

The complete details for the amplifier unit are presented in drawings 84T1-301 - 314 incl. The unit is encapsulated by means of Araldite D resin into a housing, from one end of which protrude the five generator leads as shown in dwg. 84T1-304. From the other end protrude four leads to the oscillator and two leads to the detonator, passing through the oscillator by chokes.

The circuitry is laid out with printed wiring, produced by the etched-foil process. Dwg. 84T1-309 shows details of the printed wirings on the two circular end plates in the amplifier unit. Between these two decks the tubes and the components are mounted. Connections between components and printed circuits are made by dip-soldering. Around the amplifier assembly is mounted a ring capacitor, shown in dwg. 84T1-310. This unit containing the seven largest capacitors in the circuitry is specially wound with metallized sectionalized paper and impregnated with poly-ester resin. In figure 3.34 is shown the "naked" amplifier unit with the ring capacitor before assembly while figure 3.35. shows the capacitor joined to the unit, ready to be potted into the housing, shown on the same photo. The unit is potted into

Araldite D, cold-poured with a hot after-hardening. Through the unit is an eccentric axial bore for the arming shaft. Figure 3.36 shows the complete AF unit after potting, ready for assembly of the oscillator unit.

3.33 Description of pilot production of amplifier

The mechanical parts are produced off-line in accordance with the drawings. The first step in in-line production is to prepare the amplifier housings before potting. The screws and the nuts are mounted with knurled spacers and through the 5 remaining 3 mm holes are pressed the nylon feed-throughs from the inside.

Next comes the preparation of the components. The double copper-clad bakelite raw material is cut into pieces, 10 x 6 cm large. The plates are cleaned by scrubbing with a mixture of carbon tetracloride and pumice powder, and through a silk stencil of the circuit made by a photopgraphic process a positive circuit-pattern is printed onto one side of the plates with ordinary black lithographers' ink. Each plate now contains the two circuit patterns for a complete amplifier. The printing is dried in hot air (100°C) for half an hour, and bare copper on the circuit side, as well as the copper-foiled back side, is etched away in ferric-cloride by means of a paddle-type etching machine. Etching is done with 4 plates at a time, and takes about 3 minutes on each side. Following this operation, with the black ink still atop of the circuit, the plates are hot-punched to their final shape. The ink is stripped off by washing with carbon tetracloride, a surface preservative is brushed on and allowed to dry, and all the circuit holes for the components are drilled by centering the drill into the etched holes in the copper. The plates are now ready for assembly.

The tubes for the amplifier (one tetrode, one thyratron) are coated with silastic rubber (Welvic paste grade A) by double-baking at 150°C. The radial thickness of the coating is approximately 0,8 mm. Before coating, tube spacers have been mounted to the tube pins (dwg. 84T1-313), and the pins are bent in a hook-like fashion, to ensure elasticity after final potting process.

These hooks are made in such a manner as to allow them to remain inside the coating of silastic. The tubes are then tested, and are ready for assembly. They are, as the next step, mounted into their proper place on the smallest circuit plate.

The rectifier units are also prepared, by mounting them into pairs with 0.5 M ohms voltage-divider resistors across, because inverse voltage rating for one single rectifier unit OA91 is a little too low for safe application in the power pulse.

The ring capacitor is measured, voltage-tested with 250 VDC across and between the different capacitor units, and the outside of the capacitor is insulated with adhesive tape. The leads on the oscillator side of the capacitor are soldered on in a jig.

The impact contact is assembled and shock-tested. Functioning will occur at shocks of 60 g, non-functioning at shocks of 30 g.

All other components are tested and the smaller types of metallized paper capacitors are, to save space, stripped of their wax covering and insulated with adhesive tape. As a whole, 100% testing of all components takes place, as later corrections and repairs of units are very cumbersome.

The assembly of the complete unit starts with putting the two circuit plates, 84T1-306, and the spacer 84T1-307, in a special jig, orienting the two plates exactly opposite each other and tightening the jig. Components are manually fed into their mounting holes in both plates, and ends of component leads are given a 0,5 mm bend along the circuit before cutting them. The leads from the smallest circuit plate to the ring capacitor are also mounted into this plate. Leads normally have a pressure fit into their holes. All leads, later protruding from the unit (generator-, oscillator- and detonator-leads, as well as a test-lead from thyratron grid) are cut 5 cm long. When the mounting procress has been finished, dip soldering of the smallest circuit plate takes place, with careful control of finished soldering. The ring capacitor is slid down around the unit, the capacitor leads being matched into the holes in the large circuit plate, and leads are cut. After dip soldering of the larger plate

(oscillator end) and hand-soldering of the leads from the smallest circuit plate onto the ring capacitor, the unit is ready for testing.

The performance of the amplifier unit is now tested by applying simulated generator voltages from an AC generator through a special multiple-secondary transformer (1000 - 5000 c/s) and observing the sensitivity both as a function of generator frequency and of signal frequency. If the unit is within specified limits (sensitizing frequency between 2000 and 2300 c/s, peak sensitivity 20 - 30 mV for fire) the preparation for the potting process may start.

The insulated spacer, 84T1-311, is slid down on the protruding leads from the large circuit plate, and the unit is assembled into the amplifier housing, each of the 6 leads passing either through one of the feed-throughs (5 leads) or through the ground screw, which is bored. Beeswax is dripped on the feed-throughs from the outside, and the unit is mounted into the amplifier potting jig. The amplifier housing is now potting-tight on the closed end. On the open end, the five generator leads and the thyratron grid lead protrude. Around the generator leads is mounted the nylon lead positioning fixture 84T1-312, with its top surface exactly in plane with the top of the amplifier housing. The five leads have to be manually bent to accommodate the positioning fixture. A short test procedure follows, to ensure that no short-circuits or broken circuits have been introduced.

Potting of the amplifier unit is performed at room temperature with Araldite D. During the room temperature pouring, vacuum at 100 mm Hg is employed until unit is filled with resin. After pouring, a polyethylene center plug is placed on top of the oscillator tube cavity in the housing, and room temperature hardening for 18 hours is allowed. After this time, the jig is dismounted and is ready for a new amplifier, the hardened amplifier is given a further room-temperature hardening, and after a total of 48 hours the potted amplifier is ready for test. During this test, points on the band-pass characteristic are logged, as is also the generator sensitizing frequency. In addition, observations of linearity and generator frequency ripple (normally

insignificant) are logged. Having successfully passed this test,
the amplifier is stripped of the thyratron grid lead, which is
cut beyond the potting surface, and the unit is ready for the
next in-line stage: assembly of the oscillator.

3.34 Discussion on quantity production possiblities of amplifier units

Quantity, or series production has been borne in mind
during construction of the amplifier unit. Due to the specific
100% testing of all components and balancing testing at the various
stages of assembly, the labour hours per unit are considerable.
The estimate of pilot production prices is as shown in table 3.31

Table 3.31

Pilot prices (incl. overheads)

Mechanical parts - cost of material		N.kr.	10,-
" " " " labour		"	25,-
Electronic parts - capacitors	N.kr. 100,10		
resistors	" 7,70		
rectifiers	" 12,40		
circuit plates	" 2,-		
tubes	" 27,50		
plastics	" 3,30	"	153,-
Electronic assembly - labour		"	25,-
Testing and control		"	10,-
Total pilot price		N.kr.	223,-

The total pilot price from table 3.31 is obviously high,
one of the main causes being the high price for the ring capacitor,
£4-13-6, or N.kr. 93,50. In series production of at least 2000,
a similar calculation gives a total unit price, including overheads
and profit, of N.kr. 200,-. The ring capacitor is in this case
estimated at £3-0-0, as this production rate will still be very
low for a capacitor manufacturer.

As to production facilities, there are no very critical
operations in this unit. After jigs have been produced, a few
days' introduction will enable non-skilled workers to do the work.

Many operations in the technological field are new for the Norwegian radio industry. However, with the rapid advance of knowledge of printed circuits, dip soldering and plastic encapsulation, no difficulty should be encountered in sub-contracting these units to an ordinary domestic radio manufacturer.

3.4   The R.F. oscillator unit

The R.F. oscillator unit has a double mission. It is intended for transmission of continous waves in the frequency region near 140 Mc/s, and the circuitry is so constructed as to allow received signals, reflected from the ground, to combine with the transmitted signal. This combination takes place in the plate circuit of the oscillator. When the relative velocity between fuze antenna and reflecting medium is v (m/s) and the free-space wavelength of the transmitted signal is λ (m), the reflected signal will have a frequency shift relative to the transmitted one, the shift value being

$$f_D = \frac{2 \, v}{\lambda} \ (c/s)$$

Due to the special non linear working conditions of the oscillator, a reflected, frequency-shifted signal will give rise to a low frequency component in the plate current of the oscillator tube. This current variation, still of frequency f_D, is converted into a voltage, and is fed into the input of the amplifier. A different way of explaining the functioning of the oscillator is as follows. The oscillator plate current depends on the instantaneous load on the tank circuit. In free space, load is constant, and load impedance equals that of free space (377 ohms). During approach to the target, load impedance will vary in a pulsating manner, as the fuze antenna will now be influenced by its own image behind the reflecting surface. Accordingly, the pulsating load variations will again cause current or voltage variations in the plate circuit of the oscillator.

3.41   Characteristics of unit

After this brief introduction to the oscillator unit, we will study the assembly a little more in detail. From 84T1-308

will also be seen the oscillator circuitry. The triode tube
DC69 is oscillating by means of a Colpitts coupling, consisting
of a coil and the interelectrode and leakage capacities. The
plate is RF-grounded by means of a decoupling capacitor, and the
cathode (filament) is hot due to the two R.F. chokes. The fuze
antenna constitutes an unsymmetric, broad-band short dipole. One
part of the dipole is the housings of the power unit and of the
amplifier unit of the fuze. The other part of the dipole is the
fuze base and the shell body. These two dipole halves are separ-
ated by the insulated antenna gap; a polyethylene body in which most
of the oscillator circuitry actually is situated. This antenna
is coupled across part of the oscillator tank circuit by a ceramic
capacitor. The combinations of optimized working frequency, plate
load resistor and tightness of antenna coupling was determined
experimentally. To obtain the highest value of antenna resis-
tance from this short dipole, the highest practicable frequency
has to be employed. However, at frequencies above appr. 150 Mc/s,
the triode tube employed has a very rapidly decreasing output
power, so a compromise frequency has to be chosen. The frequency
chosen for the oscillator is situated between 136 and 138 Mc/s.
As to the plate load resistor, a low value gives high plate
voltage and high Doppler current sensitivity, that is high values
of anode current variations due to antenna impedance variations.
However, the Doppler voltages will be low. At extremely high values
of load resistor, Doppler current sensitivity falls off, but
Doppler voltages may still be high. However, excessive micro-
phony in the tube may cause noise in this case. A good compromise
seems to be obtained with a load resistor of 8 k ohm. The oscilla-
tor plate feed voltage is 97 volts, and the plate current is about
5,25 mA, giving an actual plate voltage of 55 volts. Figure 3.41
shows the oscillator unit during production. The tube is
situated in the deep cavity in the amplifier housing, the rest of
the components are partly catacombed into the Modulene oscillator
mounting plate. The four R.F. chokes, two axial and to transverse
ones, will be clearly seen, as will be the Modulene bobbin for the
coil, the triple decoupling capacitor and the antenna coupling
capacitor.

The fuze body, which is actually at a high DC-potential

being directly connected through R.F. chokes to the thyratron
plate, acts at the same time as the "hot" antenna terminal, while
the "cold" end of the tank circuit is directly connected to the
ground screw in the amplifier housing.

The whole oscillator compartment is, after assembly of
the fuze base with the antenna ring around it, embedded into poly-
ethylene. This has been made possible by utilizing the fact that
the softening point of polyethylene is some $30^\circ C$ lower than that
of Super-modulene.

3.42   Drawings and detailed schematic diagrams

The oscillator unit, being directly built on to the
amplifier unit, contains very few mechanical parts. Drawings
84T1-401 - 404 incl., show the three main plastic parts. Figure
3.42 shows the parts list for the oscillator unit, and it should
be compared with the circuitry of the oscillator, shown earlier
in dwg. 84T1-308. This unit being very simple and self-explana-
tory, further comments on the circuit are unnecessary. Figure 3.43
shows all the mechanical and electronic components of the oscilla-
tor unit.

3.42   Description of pilot production

The first stage in pilot production of the oscillator is
embedment of the subminiature triode tube. The compound most suit-
able for this purpose has shown to be "NOPCO Lockfoam" with a
density of 14 lbs/cu.ft. After testing the tube, Lockfoam is
mixed, and the tube is dipped into the foam mix. Following imme-
diately on this, the tube is placed into the amplifier housing
cavity and clamped securely by means of a special flat spring.
After a few minutes, the plastic foams, and fills completely all
available space between cavity walls and tube body. The shock-
resistance of this construction has shown to be very satisfactory.

Next comes the assembly of the two axial R.F. chokes.
These are soldered to the leads from the amplifier by means of
hollow rivets, as will be clear from dwg. 84T1-304. The oscilla-
tor mounting plate, already injection-moulded in Modulene, is
secured to the screws already protruding from the finished ampli-

fier housing. The coil bobbin is wound with 1 mm dia. bare copper wire, 5 1/2 windings, and a tapping is prepared at 3 1/4 windings from the bottom, or ground terminal. The two transverse R.F. chokes are now soldered into the circuit in their catacombs, and connected to the filament pins of the tube. The coil is pressed into the key in the mounting plate, with the grid lead of the tube through the axial bore, and the two ceramic capacitors are assembled into their proper slots. Finally, solder connections to these parts are performed manually, and the oscillator unit is now ready for its first test. With the generator leads from the amplifier housing connected to the special test transformer mentioned previously the oscillator shall be active with a working frequency of 175 ± 3 mc/s. This is the only test necessary for the oscillator unit at this stage.

The arming shaft tube (84T1-404) is mounted into the base with the worm assembled into it (see later description of base assembly). After assembly of the fuze base, the embedment of the oscillator unit with polyethylene takes place in a special jig. A test of oscillator frequency is again made at the test bench, and now the correct frequency is 146 Mc/s. The oscillator section, now combined with the amplifier and the fuze base, is now ready for combination with the turbine/generator.

3.44 Series production possiblities of oscillator

As soon as suitable moulds for the plastic components have been machined, series production of parts is very easy. The assembly of the electronic part is not very critical due to the catacombing of components, but the unit is not well suited for automatic production. Hand labour is involved throughout, and a minimum total time of 2 hours has to be reckoned with.

With regard to prices for this unit, the following table 3.41 shows the estimated prices for pilot production.

Table 3.41

Pilot production prices of oscillator.

Mechanical components	- materials		N.kr.	1,-
"	"	- labour	"	5,-
Electronic components	- tube		"	13,75
"	"	- capacitors	"	4,25
"	"	- labour	"	20,-
Testing			"	5,-
	Total pilot price		N.kr.	49,-

In larger-scale series production of minimum 2000 units, a rough estimate gives a production price of appr. N.kr. 35,- including overheads and profit.

Further reduction in oscillator price would only be possible by introducing printed coil and oscillator circuitry, as well as dip-soldering of oscillator components.

3.5 The fuze base with arming and explosive devices

The base part of the fuze has a series of functions, which are briefly explained here. This part comprises the outer encapsulation around the oscillator unit, and contains the arming rotor with an electric detonator, a firing channel leading from the detonator into a booster charge, and finally the booster cup. Bore safety of the projectile is ensured by the special type of arming rotor employed. The fuze base is threaded into the projectile, and the normal threads for the PD-fuze, as well as the normal booster cavity in the M43 projectile are employed.

3.51 Characteristics and detailed drawings of unit

In dwg. 84T1-2 is shown schematically the functioning of the arming device. A worm described in chapter 3.2, driven via the arming shaft from the generator gearing, engages a worm gearing, machined into one end of the arming rotor. This arming rotor is equipped with an eccentric bore, in which is situated the electric detonator. The composition detonator is electrically fed with one terminal to detonator housing, the other to a

contact pin in the detonator end. In safe position, the
eccentric bore with the detonator is situated with a 5,3 mm
rotor wall of Dural separating it from the booster lead-in, and
the arming rotor worm gear engages the arming worm. By means of
the arming spring, the detonator pin is pressed against the Dural
body of a fixed contact assembly in the base rotor cavity, there-
by shorting the detonator effectively in the safe position. Upon
firing, the arming shaft rotates, and after arming time has
elapsed, the rotor has turned 180 degrees, whereupon the detona-
tor pin jumps into the insulated rivet in the contact assembly.
This causes the whole arming rotor to jump forwards, pressed by
the arming spring, and the worm gear disengages. The insulated
rivet and the detonator pin close the electrical connection to
the detonator, and the fuze circuit is completed. The firing
capacitor in the A.F. assembly charges, and screen grid voltage
rises gradually to a normal value with a time constant of 1 second.

In figure 3.51 are shown the different components of the
arming rotor assembly, as well as the mechanical parts of the
arming train. Drawings 84T1-501 - 509 show the details of this
complete sub-assembly.

3.52 Descriptions and specifications for the composition detonator

The composition detonator, which is a typical special
component developed for application to this project, will be
described in greater detail.

As will be seen from dwgs. 84T1-508 and -509, the
detonator consists of three metal parts; detonator pin and detona-
tor ring, separated by an insulating nylon filling and called "the
composition mix assembly", and the detonator tube. The latter is
folded over the ring as the final production step. The groove
between pin and ring is filled with a conducting composition being
composed of lead styphnate and graphite (5%). A rather high fil-
ling pressure of 3500 kg/cm^2 is desirable in order to obtain
uniform resistances.

The graphite is of the quality E 1 a from Skandinaviska
Grafitindustri A,B, Sweden. The specifications are:

Ash content: max. 1,5%

Fineness:　　at least 95% passing No. 200 standard sieve.

The lead styphnate is prepared in a laboratory scale by precipitation at 75°C from a magnesium styphnate solution. This product should meet the following specifications:

General:　It must be in the form of a bright yellow crystalline powder, composed of single crystals of uniform size approximately 0,07 mm, free from broken fragments, small particles, grit, foreign matter and visible impurities.

Lead styphnate:　The content of lead styphnate, $C_6H(NO_2)_3O_2Pb \cdot H_2O$, must not be less than 98%.

Lead:　The lead content must not exceed 44,5%.

Insoluble matter:　The matter insoluble in a 20% solution of ammonium acetate must not exceed 0,05%.

Bulk density:　The bulk density must not be less than 1,4.

Sieving requirement:　The material must not be capable of passing a No. 100 British Standard Sieve. It should have good freeflowing properties.

The _detonator tube_ is filled with 100 mg tetryl and 120 mg lead azide, both being pressed with 900 kg/cm^2. The outside of the ring is rifled before the folding operation in order to secure contact between ring and tubing.

The tetryl is of ordinary commercial quality. The lead azide is dextrinated in order to prevent the formation of long, dangerous crystals. It is prepared by a German method [9] and should meet the following specifications:

General:　It must be in the form of a white to buff powder, composed of aggregates free from needleshaped crystals having a maximum dimension greater than 0,1 mm, and free from

grit, foreign matter and visible
impurities.

Lead azide: The content of lead azide, $Pb(N_3)_2$ must
not be less than 91,5%.

Lead: The content of lead must not be less than
68,5% and not greater than 71,2%.

Solubility: The solubility in water should not exceed %.

The accepted resistance range of the finished detonators
is 75 - 300 ohms. This gives rise to a certain rejection during
production.

As to ignition specifications for this detonator, the
following data have been specified:

1) It should not be ignited by a continuous current
of 5 mA.
2) It should always be ignited when fuze is
functioning.

The first requirement is set forth to insure safety against
ignition due to the firing capacitor charging current of peak
value 0,12 mA, having to pass through the detonator. The second
requirement would usually correspond to an ignition energy of
20.000 ergs, the firing capacitor discharge energy at disposal
through the thyratron firing. However, as great variation of
fuze performance may be expected on this point, it was desirable
with an ignition energy of only 2000 ergs.

The necessary static current for ignition of detonators
with various resistance is tabulated below:

Table 3.51

Resistance, ohms :	100	200	300	400	600	800	1000	1200
Static current, mA:	58	36	24	19	13	11	10	9

Estimated energies corresponding to 1, 50 and 99% pro-
bability of ignition is tabulated below:

Table 3.52

Probability, %	Energy, ergs.	95% confidence interval, ergs.
1	150	130 - 172
50	325	300 - 352
99	700	610 - 804

These results are very satisfactory. It will however be mentioned later in some detail that a considerable increase of the ignition energy has to be expected by rough handling and after storage under unfavourable conditions.

The shock resistance of the detonators was tested in our standard shock machine. At the impact the detonator was subjected to a deceleration of 10.000 g's. This shock resulted in an increased detonator resistance. Of 40 trials the maximum increase was 100% and the average 30%. Repeated shocks resulted in further increase. After three shocks 6 of 40 detonators showed a resistance greater than 1000 ohms and 3 an unstable resistance.

The ignition energy of these detonators seemed to have increased, but none of them required a higher energy than 1600 ergs. The tubing of some detonators with high or variable resistance was removed and the resistance of the conducting composition measured. It was found that an unstable resistance always was due to deficient contact between ring and detonator tube, and that in most cases the increase of the resistance of the conducting composition was very moderate. These conclusions were based on investigations of a number of about 100 detonators at an early stage of the development.

The shock resistance of the detonators was also tested by firing the projectiles horizontally into a case of twist. With all increments of the charge the increase of the resistance varied from 0 to 30 ohms for four detonators with original resistance from 80 to 150 ohms.

It may be concluded from these investigations that the detonator is capable of standing the setback force during firing which corresponds to an acceleration of maximum 6000 g's and that even if the resistance of the detonator by greater or repeated

shocks is strongly increased, the ignition energy is not criti-
cally affected.

Accelerated climatic storage trials with the detonators
were performed by storing them alternating one day at +60°C and
one day at -40°C. After twenty days the resistance had increased
considerably. Of 20 detonators, 9 showed an increase of about
100%, 8 from 200 to 800% and 3 showed an unstable resistance.
The instability was again due to deficient contact between ring
and Dural tube.

The ignition energy of the detonators was markedly in-
creased, but all the detonators, including the unstable ones,
were ignited by an energy of maximum 1600 ergs.

The influence of humidity on the detonators was in-
vestigated by keeping them in air of approximately 100% humidity.
The first storage lasted 30 days and comprised 80 detonators.
Only the ignition energy after the storage was measured. The
energy corresponding to 90% probability of ignition was estimated
by a "staircase method"[10] to 960 ergs, the standard deviation
σ of this estimate being 75 ergs, whereas at the previous ignition
trials an energy of 495 ergs was found corresponding to the same
probability. A second storage lasted 75 days and comprised 90
detonators. The resistance was measured, and a marked increase
was again apparent. Seven detonators showed a resistance greater
than 1000 ohms (maximum 3300 ohms), the original resistance varying
from 75 to 300 ohms. The energy corresponding to 90% probability
of ignition was estimated to 975 ergs with a standard deviation of
50 ergs, a result giving no evidence of further increase of the
ignition energy by prolonged humid storage. As a final test a
few detonators were placed under water for 24 hours and sub-
sequently ignited at an energy of maximum 1600 ergs.

3.53 The rest of the firing train

Besides the composition detonator, the firing train
consists of the arming rotor, booster lead and booster pellet.

With the arming rotor in the safe position, the detona-
tor is separated from the booster lead by the 5,3 mm thick rotor
wall. Initiating trials with a simplified model of the explosive

train have been carried out in order to examine the necessary
wall thickness, and these trials indicate that with the double
amount of tetryl filling in the detonator, a wall thickness of
only 2,5 mm will effectively stop initiation of booster lead in
all tests. Trials have also been made with the fuze fixed to
the shell. The arming rotor was placed 45° out of the safe po-
sition. As expected no initiation of the booster was obtained
out of the 20 trials. By actual firing of the projectiles pre-
mature igniting of the detonator has occured due to electronic
failures, without initiation of the booster.

With the arming rotor in the _armed_ position, the deto-
nator is separated from the booster lead by only 0,3 mm of the
rotor wall. Initiating trials with the simplified model of the
explosive train were carried out in order to determine the maximum
wall thickness giving initiation of the booster. With 80% of the
normal tetryl filling in the detonator, 7 out of 7 tests gave
booster initiation through a wall of 1,0 mm Dural. The results
indicate that the dependability of the explosive train is satis-
factory. By actual firing of the projectiles no indication of
non-functioning of the explosive train has been observed.

The _booster lead_ consists of about 30 mg tetryl com-
pressed with 900 kg/cm² into the threaded hole in the fuze base,
and filling is covered with shellac.

The booster of the original impact fuze M52 is a 15 g
tetryl pellet. In the NDRE-fuze the threaded part of the fuze
base is so large that a normal booster would advance too far
into the cavity in the projectile. In order to satisfy the
requirement of interchangeability the size of the booster had to
be reduced to 11 g. Bursting trials have indicated that this
reduction does not affect the high order detonation of the main
charge.

3.54 Pilot production of the base assembly and completion of fuze

The fuze base is the only mechanical component of this
fuze which requires tolerances difficult to achieve during pro-
duction on a small scale. The mechanical parts are made accord-
ing to drawings, and half way through the machining processes,
the Supermodulene ring is moulded onto the Dural back base. The

rest of the base machining is then carried out, and the component
is controlled carefully, especially as to the degree of engage-
ment between the worm and the worm gearing on the arming rotor.
A threaded hole in the side of the base ensures contact to a
ground lead to be connected later. The fixed contact assembly,
84T1-502, is completed, pressed into position in the base, and
a special 1 mm rivet is inserted from the "oscillator cavity" in
the base. The base worm, 84T1-206, is mounted into the tube,
84T1-404, and these two parts pressed into the fuze base. The
tube acts both as a bearing for the worm and as a guard later
during encapsulation, to prevent polyethylene entering the arming
chain. The top of the tube is automatically pressed tighly into
the oscillator mounting plate during assembly.

The base is now assembled to the oscillator end of the
finished amplifier, and the two leads from the axial R.F. chokes
are connected to the base, one by the ground screw with a spring
washer and one by soldering to the insulated rivet in the fixed-
contact assembly. The free end of this contact assembly is coated
by besswax-dripping. The antenna ring is secured to the ampli-
fier housing by means of the amplifier retaining ring, 84T1-302,
shown earlier. The oscillator is now tested as to activity, and
the final oscillator embedment with normal, highpressure poly-
ethylene follows by injection through the 5 mm bore in the side
of the antenna ring.

The combined amplifier-oscillator-base unit is now
joined to the generator unit, after first mounting the arming
shaft into its position through the amplifier. Connections from
arming shaft to worm and worm gear in both ends are self-centering
by splines. The generator is positioned down onto the amplifier
unit by two nylon positioning pins, and the five leads from the
amplifier will, after having been cut to the correct length,
engage their proper holes in the generator contact assembly. Here
already the five generator connections protrude radially. A drop
of solder is heated onto each of the five connections, and genera-
tor leads are cut. Molten beeswax is then dripped into these
holes, and the turbine housing is firmly secured around the gene-
rator unit, pressing this unit on to the top of the amplifier
housing.

A complete electrical test with the fuze in its present state is now carried out. A dummy detonator, made of bakelite and containing a 4,7 k ohms resistor, which closes the contact from firing capacitor to thyratron plate, is inserted into the arming rotor cavity. The fuze is inserted into the test box, earlier shown in figure 2.13, and the sensitivity of the unit is observed. If the sensitivity, at three different tests, is found to remain between 3,0 and 4,5 relative units, the fuze is provisionally accepted, it is then shock-tested at 8000 g's, and box-tested once more. Having again passed this test with the same sensitivity as before, the fuze is finally accepted, and no further tests are performed with it until firing. Atop of the threads on the amplifier housing a thin layer of Araldite D is applied to lock the turbine housing and the retaining ring.

The last mechanical operation includes completion of the arming and firing train. The detonator is produced by pressing the conducting composition mix described in section 3.52 into the groove of the "mix assembly" in a special jig. Composition resistance is measured, and assembly is discarded if outside tolerance limits 75 and 300 ohms. The detonator tube is filled primarily with 100 mg tetryl and secondarily with 120 mg lead azide, pressed into the tube in a jig assembly.

The composition ring in the mix assembly is rifled on the outer surface in a special tool. The ring is pressed into the filled detonator tube, and the latter folded over the nylon filling in the ring. The detonator unit is then ready for testing and subsequent mounting, and is inserted into the arming rotor with the detonator pin extending outwards.

Into the firing channel is pressed a filling of 30 mg tetryl, tooling pressure 900 kg/cm^2, and the filling on the booster end is covered with shellac. The booster pellet, pressed from 11 g tetryl, tooling pressure 700 kg/cm^2, is further produced and inserted into the booster cup.

The arming rotor with detonator may then be inserted into the bore in the fuze base, with detonator eccentric from the booster end. A missing tooth on the arming rotor, fitting a "bimple" in the fuze base assures the correct, safe position.

The arming plug with its spring is tightened and secured by a
layer of mica-filled Araldite D.

Immediately before firing, the booster cup with pellet
is assembled to the fuze, and the fuze threaded into the projec-
tile body. This last precaution has always been taken during
pilot production, although in series production the complete round
will be packaged ready for firing, at the assembling manufacturer s.

3.55 Quantity-production of base section

The base part is after the necessary tooling has been
made available well suited to production in larger series. A
suggestion of the pilot production prices will be seen from
table 3.51.

Table 3.51

Pilot prices of base section and completion of fuze

Mechanical parts - materials	N.kr.	4,-
labour	"	26,-
Assembly and testing of detonator	"	3,-
Plastic moulding of unit	"	6,-
Electronic completion of fuze - labour	"	5,-
Testing	"	15,-
Total pilot price	N.kr.	59,-

It is assumed, that during larger series production of
for instance 2000 units, a unit price of N.kr. 40,- may be
achieved.

As to production facilities, chiefly mechanical work is
involved, and this is easily done by the precision mechanical
industry. The laboration and testing of detonators may most pract-
ically be performed at Raufoss Ammunition Factories in Norway,
whilst the electronic completion of the fuze should be performed
at the same plant which assembles the rest of the electronics for
the fuze.

3.6   The whole integrated fuze viewed as one unit

In this last section of the descriptive chapter, some considerations will be presented on the complete fuze as to production prices, production facilities and possible points where advantage may be gained by simplification reducing the total fuze price.

3.61   Total production price of fuze

From the preceding chapters, a production price is estimated for each sub-assembly, including overheads and a normal profit. In table 3.61 is given a survey of these production prices.

Table 3.61

Estimated production prices of fuze

Generator unit	N.kr.	85,-
Reduction gearing assembly	"	10,-
A.F. unit	"	200,-
Oscillator unit	"	35,-
Base, final assembly, testing	"	40,-
Total production price	N.kr.	370,-

This price estimate is hoped to be approximately correct provided a series of at least 2000 fuze units. It might be very interesting to compare the price of a VT-fuzed projectile M43 with a PD-fuzed M43. Norwegian production prices for the PD-fuzed mortar projectile M43 are N.kr. 75,- for the shell body, and N.kr. 25,- for the fuze. Accordingly, a PD-fuzed M43 costs N.kr. 100,-, while a VT-fuzed shell will be priced at N.kr. 445,-. In other words, a price increase factor of 4.5 has to be accounted for by savings in transport, increase of firing effectivity and savings in necessary manpower.

3.62   Production facilities as to different sub-units in Norway

Here will be summarized our views on production facilities presented during description of the different units earlier in this report.

The mechanical components may be readily produced by sub-contractors from the civilian industry, or possibly at Raufoss Ammunition Factories. However, for series smaller than 5000 fuzes, it is suggested that the cheapest and most time-saving solution will be sub-contracting, preferably to many industrial firms, collecting the components at the radio plant in charge of the electronic assemblies. The electronic sub-assemblies of the generator, amplifier, oscillator and base units may be performed in a special, closed department of one of the domestic radio manufacturers', or most preferably in a new plant organized fully for fuze production, employing f.ex. appx 50 workers. This plant would then be able to produce a quantity of approximately 20 fuzes per day, or the estimated 2000-series in between 3 and 4 months' time. The explosive assembly, as well as final inspection and sealing into containers would preferably at all events be performed at the Raufoss Ammunition Factories.

3.63 Advantages to be gained by possible technological simplification

From table 3.61 it will be clear that the production price of this fuze is high. There are three units where prices might be drastically reduced by redesign. The generator unit, with estimated production price of N.kr. 85,-, should by extreme simplification and utilization of cheap, non-critical parts be able to be produced at N.kr. 25.- per unit. This simplification must then include change-over from roller bearings to Oilite bearings, as well as elimination of the critical tolerances of the unit, especially the position of the rotor in the stator laminations. By elimination of the ring capacitor, and by still more mechanized production in the amplifier unit, this unit may be redesigned to cost approximately N.kr. 150.-. The oscillator unit might likewise be simplified by application of printed R.F. wiring and mechanized production, and may end up with a production price of N.kr. 20.-. In total, the results of a simplification and mechanization program may give us a production cost of N.kr. 250.-, still retaining the same main design features as presented earlier in this chapter.

Naturally, a simplification program connected to this fuze program is more than an economical one. A reduction of the close tolerances, for example, would enable more "common" mechanical plants to cooperate as sub-contractors. A rush production might also be realized in emergency cases, by taking advantage of the possibilities of sub-contracting down to the individual components. This would make a very short "dead time" from start of off-line production until the first units are ready for firing possible.

4.0 TEST SPECIFICATIONS FOR THE NDRE MORTAR FUZE

These specifications are set out according to the recommendations in annex to NATO document AC/72-D/37 from the 40/70 ammunition panel[11]. Some of the specifications have been omitted, due to the fact that there are significant differences between 40 mm AA fuzes and VT-fuzes for mortars. Some specifications have also been added or modified. The tests have all successfully been performed with the NDRE fuze, with exception of the climatic test, which has not been possible to carry out due to lack of a suitable climatic chamber, and the 8000 g's shock test, which has up till now been performed at 5000 g's, due to certain weak points during the pilot production.

4.1 Drop tests

a) Test of fuzes alone

Drop in a 30 kg steel block on to a steel anvil from a height of 3,75 metres, with a rebound of 30 per cent of this height:

4 fuzes nose down
4 fuzes sideways, arming plug down
4 fuzes base down.

Filled fuzes are to be used, but the booster pellet may be replaced by a wooden pellet.

Results to be obtained: During this test fuzes must NOT function. After this test fuzes must be safe to handle and to fire, but need NOT remain "serviceable".

Total test queantity: 12 fuzes.

b)   Test of fuzes in a complete round

Drop 5 rounds nose down, guided to assure
verticality, on to an armoured plate from a
height of 10 metres. Filled fuzes are to be
used, but the booster pellet may be replaced
by a wooden pellet. Primers, cartridges and
supplementary charges, as well as shell
fillings are to be replaced by inert materials
to make up the correct weight of the service
round.

Results to be obtained: After this test
fuzes must be safe to handle and to be disposed
of. No explosive element shall burn or detonate.
The fuzes need NOT remain "serviceable".

Total test quantity: 5 rounds with inert
fillings.

4.2 Vibration tests

Vibrate

4 fuzes base down

4 fuzes sideways, arming plug up

4 fuzes sideways, arming plug horizontal

at 1,5 millimetres out to out at 20 cps for 8 hours. The fuzes
are to be at ambient temperature. Boosters will not be fitted.

Results to be obtained: After this test and the tests
in 4,3 and 4,4, fuzes must remain "serviceable", according to
4.7 and 4,8.

Total test quantity: 12 fuzes.

4.3 Climatic tests

The 12 complete fuzes, tested according to 4.2, with
boosters assembled, are to be cycled in climatic chamber for 7
days between -40°C dry cold and 60°C at 95% relative humidity,
each climatic setting lasting for 12 hours.

Results to be obtained: After this test and the test
in 4,4 fuzes must be "serviceable" according to 4.7 and 4.8.

4.4 Shock tests for functioning

The fuzes having been tested according to 4,2 and 4.3
are to be shock tested in a bumping machine, giving 8000 g's

by drop from an elevation of 5 metres against an oil-braked piston.
The boosters are to be unscrewed.

Results to be obtained: After this test fuzes must be
"serviceable" according to 4.7 and 4.8.

4.5 Functioning tests of explosive train

10 fuzes in the armed position, with firing leads
connected to the detonator, are to be mounted in TNT-filled
shells complete with booster charges. The rest of the fuze except
for the base part may be replaced by a dummy with the same weight.
Shells and fuzes are kept at $-40^{\circ}C$.

Results to be obtained: During this test all explosive
elements must detonate.

Total test quantity: 10 rounds with modified detonator
and fuze.

4.6 Non-functioning tests of explosive train

10 fuzes in the safe position, but with the arming
rotor being displaced 45° mechanically from the normal "safe"
position, are to be mounted in TNT-filled shells complete with
booster charges. The rest of the fuze except for the base part
of it may be replaced by a dummy with the same weight. Shells
and fuzes are held at $+60^{\circ}C$. Detonators are fired electrically.

Results to be obtained: During this test no explosive
element beyond the detonator must burn or detonate.

Total test quantity: 10 rounds with modified detonator
and fuze.

4.7 Standard sensitivity test

The 12 fuzes tested according to 4.2 and 4.3 are to be
mounted in the standard sensitivity box, after booster cup and
firing channel filling have been omitted. The sensitivity box is
fed with a 100 cps signal, 15 V rms. The generator is driven to
a speed giving 2500 cps electrically (37500 rpm), whilst the
arming rotor is replaced by a dummy rotor, having 3000 ohms
resistance internally and being firmly connected to base.

Results to be obtained: At least 9 out of the 12
fuzes will show a standard sensitivity between 3,0 and 4,5.

No fuzes shall yield a higher sensitivity than 6,0.

4.8 Firing test

The 12 fuzes, having passed the tests according to 4.2,
4.3 and 4.7, are to be mounted in complete rounds with refilled
firing channels, remounted boosters and TNT-filled shells. These
12 rounds are fired above sea water with a mortar elevation of 65°,
5 charge increments being provided. At least 8 rounds shall
detonate in a height of between 4 and 8 metres.

5.0 RESULTS OF PROVING GROUND TESTS WITH THE NDRE-FUZE

A total of 16 different field tests with firing or
airplane dropping of fuzes or components of it have been per-
formed. In table 5.1 is given a short summary of the intention
with the tests, while the results are discussed in some details
further on in this chapter.

Table 5.1

Summary of fuze field tests

Nr.	Date	Intention	Tested specimen
1	19/10-53	External-ballistic stability	33 dummy fuzes
2	8/6 -54	Turbine-generator tests	4 generators dropped in dummy bombs from plane
3	17/2 -55	Turbine-generator tests	5 rounds with generators, dropped from plane
4	15/3 - 55	External-ballistic stability	6 rounds PD-M43A1 12 rounds dummies with generators
5	29/3 -55	External-ballistic stability	10 rounds, shells with different shaped fuze
6	27/4 -55	External-ballistic stability	12 rounds PD-fuzed M43A1 10 rounds with modified fuze shape
7	27/6 -55	External-ballistic stability	13 rounds modified shape, of these 5 generator-telemetered types
8	5/9 -55	Noise studies during flight	3 VT-fuzed rounds
9	14/9 -55	Noise studies	6 VT-fuzed rounds 3 electr. impact rounds
10	29/9 -55	Functioning tests	4 VT-fuzed rounds, 2 electr. impact rounds
11	17/10-55	Functioning tests	2 dummies with oscillators 6 VT-fuzed rounds
12	16/2 -56	Funtioning tests	5 dummies 10 VT-fuzed rounds
13	27/3 -56	Functioning tests	4 dummies 8 VT-fuzed rounds
14	12/7 -56	Functioning tests	10 VT-fuzed rounds
15	4/10-56	Functioning tests	20 VT-fuzed rounds
16	17/12-56	Functioning tests	23 VT-fuzed TNT-rounds

From table 5.1 will be seen, that the proving ground tests may be classified into 4 different time-phases. Tests nos. 1-3 indicate the preliminary studies of the power unit, and the results of test no. 3 starts the external-ballistic phase. This section comprises test nos. 4-7. Then tests nos. 8 and 9 characterize the wobbulation phase, where noise due to wobbulation of

the turbine-generator was studied. An finally, tests nos. 10-16 are firing tests for _functioning_. Apart from these proving ground tests with fuzed projectiles, _terminal ballistics_ tests have been performed, to determine the optimum burst height above different terrains.

5.1   _Proving ground tests nos. 1-7_

At the very first start of the project, a preliminary sketch of the shape of the fuze was made, and a rough estimate as to the fuze weight was likewise made. _Test no. 1_ gave the starting data, that a fuze with the assumed main ballistic specifications, would introduce no flight instability on a _Norwegian_ 81 mm shell type, fired with 2 supplementary charges.

During _test no. 2_, 4 bombs, with turbine-generators in their noses, and with telemetering transmitters, were dropped from 3000 ft. height by a helicopter. The turbine velocity was recorded, and preliminary construction data for the generator were established.

Test no. 3 was intended to study the generator wobbulation during airplane drops of complete 81 mm rounds, with dummy fuze, turbine-generator and telemetering facilities for recording of the diminutive changes of generator frequency versus time. The results were rather sad, the projectiles were unstable, and tumbled during descent, so no useful recordings were achieved. This test revealed the fact, that the fuzed projectiles were now unstable during flight, and this would have to be remedied until further generator data could be obtained.

During _test no. 4_, we tried the stability by actual firing projectiles with generator-powered dummies. Some of the rounds had a longer tail than the normal one. However, it was again evident that flight stability was very poor.

Test no. 5 was sort of seeking in the dark for possible solutions on our problem of stability. In _figure 5.11_ is shown a photograph of the 10 rounds, with different fuze weights and shapes. Some increase in stability was observed, this was achieved by increasing the fuze weight, and thereby shifting forewards the center of gravity of the complete round.

The result from <u>test no. 6</u> was still an increase in stability, especially on those rounds where the front end of the fuze was plane.

And finally during this phase, <u>test no. 7</u> indicated that our new modifications regarding weight,, shape and center of gravity gave a flight stability at least as good as that of an ordinary PD-fuzed round.

5.2 <u>Proving ground tests nos. 8 and 9</u>

Stability was now obtained, and the wobbulation characteristics of the generator was again investigated. In <u>test no. 8</u>, we observed that it was not possible at this technologial state, to pass the two difficult points in the trajectory; immediately after firing and at the top of the trajectory. Noise signals occurred of a magnitude large enough to fire the fuze.

During <u>test no. 9</u>, 1 out of the 6 VT-fuzed shells showed a normal proximity-action, 2 were duds, while 3 were prematures. At the same time, the impact contact intended for the amplifier was tested for the first time, and two out of three functioned. However, this test was the first one to reveal a normal functioning of the NDRE-fuze.

5.3 <u>Proving ground functioning tests nos. 10-16</u>

It now seemed that only smaller adjustments and technological modifications were necessary in order to make the fuze function on a larger scale. During <u>test no. 10</u>, 2 VT-fuzes functioned, and 2 were duds. One out of two impact fuzes functioned.

During <u>test no. 11</u> the VT-results were 1 functioning, and 5 prematures. The conclusions were now, that with the sensitivity necessary for optimum height of burst, too much noise, originating mainly from the gear trains and through the rectifier section, would fire the thyratron during flight.

A long period of laboratory investigations followed, until the sources of noise were found and means for overcoming it were introduced. For <u>test no. 12</u>, 10 VT-fuzes were made according to the results of these investigations, and the test

resulted in 4 fuzes functioning, 4 were prematures and 2 duds. Smaller modifications in the generator construction and in the amplifier circuitry were again introduced.

The results from test no. 13 were 3 fuzes functioning, 1 was premature and 4 duds. Still we did not manage to take all necessary precautions during pilot production, and too many weak points were invoidable.

Test no. 14 gave a far better result. The 10 VT-fuzed firings gave 7 functionings, 1 premature and 2 duds. During production, however, 7 more fuzes were wrecked after one or more of the tests, so it was still obvious that we did not yet manage the pilot production.

Test no. 15 gave as a result, that out of a series of 23 fuzes attempted, 20 passed the final test. Firings resulted in 15 fuzes functioning (75%), 2 were premature and 3 duds. The results were very promising, but still   constructional points remained which were not satisfactory, although the wreckage percentage during production was now very low. Figure 5.41 shows magnification of film recordings for 4 successful rounds.

Production of fuzes for test no. 16 once more showed a high percentage of fuzes passing final laboratory test. From an original number of 26 amplifier sub-units, 23 fuzes resulted. The results of firing, however, were this time not very satis-factory. 10 fuzes functioned, 7 were prematures and 6 duds. One of the duds, however, detonated at impact as intended. The tests this time were the most realistic ones, TNT-filled shells were used for the first time, and 5 of the firings were performed with charge 5, which gives the very large acceleration of about 5000 g's. The prematures were partly due to these large accelerations, and also indicated noise voltages occurring more strongly than before. The main result of this test will be, that minor mechanical changes during firing resulted in unstable fuzes, and that these faults will be relatively easy to remedy. Full reports on the different firing tests are available.

5.4   Terminal ballistic tests

As described in section 2.4 it was found by static
bursting of mortar shells that the number of casualties by air
bursts in optimum height was increased by a factor of 3,6 for
targets flush with the surface and by a factor of 7,7 for
targets in medium deep trenches compared with ground bursts.

These figures are lower than estimated by American
investigators in the official history of the Office of Scientific
Research and Development[12]. It is here believed that proximity
fuzes would increase the effectiveness of 81 mm mortar fire by
from ten- to twenty-fold. Most of the investigations referred
to in section 2.4 on the other types of ammunition also resulted
in greater advantage factors than obtained by us. Although
higher figures might be expected on account of the larger shells
used, the difference is unreasonably great. In those trials,
however, where the effect of blast for the surface burst was in-
cluded in the evaluation, lower figures were obtained than by us.
It is therefore thought that the advantage factor of 20 quoted for
260 and 500 lbs bombs in the case of men in shallow trenches is an
overstatement due to disregard of the blast effect.

The greatest advantage of air bursts is expected on
snowcovered ground where projectiles with impact fuzes are reported
to have only slight effect. As no bursting trials have been
carried out, an estimate of the advantage factor has to be very
uncertain. It does not seem doubtful that an advantage factor of
20 or even more, as suggested in section 2.4, may occur, but as
the factor is greatly dependent on snow conditions and on the tac-
tical situation, it is very difficult to predict how often such
high figures will be obtained.

Besides snow-covered ground there are several other
circumstances which are unfavourable for impact fuzes, for instance
boggy land or very rocky ground where oblique impact may cause duds.

An advantage of the proximity fuze which is difficult to
evaluate quantitatively, is the psychological effect. It is well
known that air bursts have a detrimental effect on the morale of
troops in trenches. On the other side it has been reported verbally

that troops accustomed to winter warfare completely neglect mortar
fire with impact fuzes in deep, loose snow. It is therefore
thought that the psychological effect ought to be allowed for in
those cases where the tactical advantage of impact and proximity
fuzes otherwise is equal.

6.0 <u>CONCLUSIONS</u>

In this final chapter, some operational analytic points
concerning the possible advantage obtained by applying VT-fuzes
instead of PD-fuzes in certain situations are discussed. Further
the background philiosophy and an evaluation of the NDRE- VT-fuze
is given. Lastly, the present stage of development is viewed in
perspective and possible future activity as regards mortar fuzes is
briefly outlined. Finally, acknowledgments are given to
colleagues engaged on the project.

6.1 <u>Operational analytic views on effectiveness of mortar fire</u>

This section commences with some assumptions as to the
purpose of mortar fire in attack and defence. Then the results
of some computations are given. These computations are based
upon the results of the terminal-ballistic test mentioned earlier
in sections 2.41 adn 2.42 above, and give the loss percentage
per shell for different burst heights in various tactical situations
For the NDRE VT-fuze, the results of these computations are eva-
luated, and with the sensitivity setting earlier referred to
(section 2.52 above), the loss percentage per VT-round may be
compared with the PD-round. The problem of projectile transpor-
tation is examined by tactical examples, and it is concluded that,
although the range reduction incurred by appliance of VT-fuze is
taken into account, even very small hand-carrying distances will
favour VT-fuzes, thus giving a larger capacity of destruction
per mortar soldier.

6.11 Tactical application of 81 mm mortar fire

The 81 mm mortar is used as a close-range support to
the heavy infantry in attack and defence. Six mortars with the
necessary personnel and with transportation facilities are

included in the Heavy Weapons Company of the Infantry
Battalion as a Mortar Platoon.

In <u>attack</u> the mortars will be used to neutralize
enemy activities, i.e. to prevent the enemy from firing his
weapons and to reduce the effectivity of his supply lines.
Because of the lack of accuracy, the mortars are of little value
when used against point targets, which must be destroyed by
other means.

In <u>defence</u> the mortars will give barrage (fire) against
enemy concentration areas and supply lines. The most important
task is, however, to launch such a destructive fire against the
important areas across which the enemy has to advance, so that a
crossing is made very expensive or even impossible for the in-
truder. A task of this kind is called an "SOS fire task".

It is seen that the main purpose of the mortar fire is
to hinder or stop enemy activities, not primarily to destruct him.
On the other hand, this is only achieved if it is made very risky
not to seek shelter from the mortar fire. In other words, a great
destructive potential is also a necessity. It is also known that
the tactics of some nations is to accept far greater losses than
ordinarily accounted for, and this stresses the importance of the
destructiveness of mortar fire in <u>all</u> tactical situations.

In future wars, especially in countries like Norway,
mobility and independence of the road system is of paramount in-
portance. Since it is virtually impossible to transport for a
greater distance a heavy gun outside the roads, this gives the
mortar a still more important role. If mortars are to be
substituted for artillery, ammunition supply lines will be given
an even more difficult task than to-day. The resupply of ammu-
nition seems to be the major problem to be solved before mortars
can play their full part in modern warfare.

6.12 Loss percentage per round, experiments and calculations

Lack of time has made it impossible during this project
to undertake the series of experiments necessary to give an accu-
rate assessment of the effectiveness of the NDRE-fuze.

The experiments, however, which have been performed are described earlier in sections 2.41 and 2.42 above, and will be briefly recapitulated here. The general layout was the following: The targets were wooden rectangles 0,4 m x 1,8 m and of 1,3 cm thickness. They were arranged in a square net with sides equal to 5 metres. In one case, called Case B, the targets were placed on a plane field. In the other case, called Case A, the targets were placed at the bottom of 50 cm deep trenches spaced across the same plane field. Mortar shells with an inclination of 66° towards the ground were fired statically in the center of the array. The height of detonation, to be denoted by h_D, was varied between 0 metres and 12 metres, and 7 shells were detonated for each h_D. In each case the number of fragments penetrating the targets were counted. One penetration in a target rectangle was counted as a 50% probability of incapacitation, two penetrations as a 75% probability and so on. The effects of the shock wave has also been assessed . The expected number of incapacitations per shell were then computed as a function of h_D.

An SOS fire task is usually launched against an area of approximately 100 m x 100 m, which in the tactical situation de-scribed above will contain 400 targets. Hence, if we divide the expected number of incapacitations per shell by 400, we will get the approximate expected percentage of loss per shell inflicted on the enemy. These percentages will, however, also be valid if concentration of enemy personnel is smaller or greater than assumed above. They may also be applied if it is assumed that the mortar fire is evenly distributed throughout the area and that nothing is known about the distribution of the enemy within the area.

In addition to this, it has been attempted to apply the results of Case B to make a simple comparative computation of the loss percentages against standing (erect) personnel, given as Case C below.

Table 6.11 below gives the results of the experiments and of the computations (after smoothing). The percentage of loss in-flicted on the enemy per shell detonating at the height h_D will be denoted by p_{h_D}.

Table 6.11

Loss percentages per shell

Burst height h_D (metres)	Case A 50 cm entrenched personnel $p_{h_D}\%$	Case B lying personnel $p_{h_D}\%$	Case C erect personnel $p_{h_D}\%$
0	0,022	0,30	3,5
1,5	0,07	0,69	3,8
3,0	0,12	1,06	2,9
4,5	0,13	0,87	2,1
6,0	0,15	0,69	1,4
7,5	0,13	0,55	1,0
9,0	0,10	0,47	0,7
10,5	0,08	0,39	0,5
12,0	0,06	0,30	0,4

The results of the last column (Case C) must be regarded as more inaccurate than the other results. It has been assumed that all the targets are facing the point of detonation, and this should introduce a correction factor of approximately 0,75. It has also been assumed that the values of p in Case C are approximately equal for h_D equal to 0 and to 2 metres. An accurate compensation for the effects of more penetrations of the targets has not been possible in table 6.11.

From the percentage of loss per shell it is possible to compute the number of shells which must be fired against the 100 m x 100 m area to cause a given percentage of enemy losses. In table 6.12 below, the number of shells necessary to cause 50% enemy losses, N_{50}, is calculated as a function of the loss percentage per shell p. The calculations are based upon the formula

$$N_{50} = - \frac{\log 2}{\log (1-p)}$$

Table 6.12

Shell numbers for 50% enemy losses

p	N_{50}
0,1	753
0,2	334
0,3	232
0,4	177
0,5	137
0,6	116
0,7	97
0,8	86
0,9	77
1,0	68
1,2	58
1,4	49
1,6	43
1,8	38
2,0	34
2,4	28
2,8	24
3,2	21
3,6	19
4,0	17

6.13 Comparison between the PD and the VT-fuze, advantage ratio

From table 6.11 it will be obvious that detonation above ground is favourable for the cases A and B. The specified setting of the NDRE-fuze, 4,5 metres above average terrain, turns out to give good results in both cases.

When the percentage of loss per <u>VT-fuzed round</u> is computed, attention must be paid to the dispersion in height of detonation and to the percentage of non-functioning fuzes. We will assume that 50% of the proper functioning VT-fuzes detonate in a height of 4,5 metres, 25% in 3,0 metres and 25% in 6,0 metres. We will further assume that 80% of the total number of fuzes will function properly and that 15% will give impact detonation. This gives the following formula for the percentage of loss p_{VT}, per VT-ruzed round:

$$p_{VT} = 0,2\ p_{6,0} + 0,4\ p_{4,5} + 0,2\ p_{3,0} + 0,15\ p_{0,0}$$

An evaluation of the VT-fuze must also take into account the reduced range for a VT-round, 1600 metres, as compared with the range 2400 metres when PD-fuze is applied.

For the <u>PD-fuzed round</u>, experiments and computations, as depicted in table 6.11 above indicate the rather high value of $p_{PD} = p_{0,0} = 3,5$ in Case 6. As is mentioned above, this figure must be regarded with considerable reservation. The only other source of information which has been available is the journal "Infanterinytt", No. 1, 1951[13]. On page 9 is stated that 80 shells uniformly distributed on a target area of 100 x 100 metres will cause 50% losses. From table 6.12 we find that this gives a $p_{0,0}$ equal to 0,86%. This figure is stated as being valid against living targets without shelter in open terrain. Northing is said about how the figure was obtained.

It is felt, however, that our experiments and computations give a too optimistic picture of the effectiveness of the PD-fuzed round. Even very small departures from the plane field introduce shadowing effects which greatly reduces p_{PD}. An obstacle of height 0,5 metres at a distance of 2 metres from the point of detonation and with a projection of 1 metre in a plane normal to a ray from the point of detonation will for instance reduce p_{PD} by 7 - 9% in both Case A, B and C above.

No precise information concerning the behaviour of PD-fuzes in snow has been available. However, it is easily shown that even small depths of detonation below the snow surface may introduce severe shadowing effects in Case C. If it is assumed

that as an average, fragments which have passed less than 1 metre through snow still have their full effectiveness, while the other fragments are absorbed, we obtain the following table 6.13, where the value of $p_{0,0}$ = 3,5 from table 6.11 is used for Case C.

Table 6.13

Reduction of effectiveness

h_D (metres)	p_{PD} (%)
0,0	3,5
-0,1	2,2
-0,2	0,64

The calculations are very simplified, but still serve as an indication of the sensitivity of the PD-fuze in these circumstances. In the cases A and B, even greater reductions in effectiveness are introduced.

We will now try to compare a VT-fuzed and a PD-fuzed mortar round on the basis of the assumptions above. Principally, there are two significant ratios describing the behaviour, the cost ratio and the tactical advantage ratio.

From the calculated production costs in chapter 3.61 in this report, a price increase factor or cost ratio of 4,5 has to be taken into account.

The loss percentage per round for V - and PD-fuzed shells are calculated below in table 6,14, as well as the advantage ratio r.

Table 6.14

Loss percentages and advantage ratios

Case	p_{VT}	p_{PD}	$r = \dfrac{p_{VT}}{p_{PD}}$
A	0,12	0,022	5,4
B	0,74	0,30	2,5
C	2,2	3,5	0,63

As mentioned above, it is feared that our computations and experiments give too much favour to the PD-fuze. The effectiveness of the PD-fuze is rapidly reduced by the introduction of even small obstacles or by detonation below snow surfaces, while the effectiveness of the VT-fuze is kept almost constant during those same conditions.

6.14 Tactical viewpoints, the transportation problems

An "SOS fire task" is defined as rapid fire, 20 shells per minute for 2 minutes, and thereafter fire at the rate of 10 shells per minute. The fire is delivered by 2, 4 or 6 mortars against a 100 x 100 metres target area. As a unity for mortar fire we will make a more precise definition: By an "SOS-task" we understand fire delivered against a 100 x 100 metres area by 2 mortars, 20 shells per minute per mortar during the first 2 minutes followed by 10 shells per minute per mortar for 2 minutes.

This gives a total of 60 shells per mortar, which correspond to the number of shells usually transported together with the mortar in its jeep. The total number of shells required for an SOS-task then amounts to 120.

The purpose of an SOS-task is to stop enemy advance. We may assume that an enemy will try to cross the target as quickly as possible. If he is advancing at a speed of 3 metres per second, he will cross the dangerous area in 30 seconds, and 20 shells will be fired against him during this time if an SOS-task is delivered. If the rather pessimistic loss percentage of 0,86 per shell is assumed as quoted above, the resulting total loss wil amount only to 16%. This figure includes not only mortal injuries, but all degrees of incapacitation. From our knowledge of enemy tactics, it will be obvious that a greater rate of fire is necessary. If 4 mortars are given the same SOS-task, the above tactical situation will result in a 30% loss, while 40% loss may be obtained if all 6 mortars of the platoon are in fire.

As the unit for the transportation capacity of the different methods for ammunition supply, we will use "shell-kilometer per hour". If a vehicle may carry N shells at a speed of x km/hour, its transportation capacity (abbreviated to TC) is

1/2Nx. The factor 1/2 enters because of the return trips. The TC divided by the length of transport path gives the supply capacity (SC) in shells/hour. In table 6.15 the TC of some transportation methods have been approximately estimated.

Table 6.15

Transportation capacity

Shell-carrying soldier	7,5	shell-km/hour
Horse	30	"
Jeep on road	1900	"
Jeep in terrain	750	"
2 1/2 ton truck	12500	"

It is seen that the transportation of ammunition outside the roads represents a very serious problem, since a sufficient number of carrying soldiers will seldom be available.

As an example, let us assume that the shells have to be transported on road 10 km and then carried 5 km. The 6 jeeps of the mortar platoon are then able to deliver 1140 shells per hour, or 9,5 SOS-task units per hour. Each soldier is able to deliver 1,5 shell per hour at the end of the chain, and 80 soldiers are required to carry 1 SOS-task unit of fire volume per hour. Since only between 10 and 30 soldiers are available for carrying purposes, this demonstrates the lack of balance in the transportation chain and that a greater TC outside roads is a necessity.

The importance of the VT-fuze in this respect is that in many situations it gives greater fire-power per shell. Hence the amount of ammunition required for certain tasks is reduced. Since each shell represents r times the loss percentage of a PD-fuzed shell, the TC of each method of transportation may be said to have been multiplied by a factor r as far as this task is concerned.

In this connection, the effects of the reduced range of the VT-fuzed rounds must be discussed. If we want to deliver fire on a target at a distance of x kilometres from where the motorized transport chain stops, the PD-fuzed shells must be

carried (x - 2,4) kilometres. The VT-fuzed shells have to be
carried (x - 1,6) kilometres. On the other hand each VT-fuzed
shell is the equivalent of r PD-fuzed shells. Assuming that N
soldiers are used for shell transport, we obtain SC of the tran-
sport chain for PD-rounds:

$$SC_{PD} = \frac{7,5\ N}{x - 2,4}$$

When VT-fuzes are applied, the value of SC will be:

$$SC_{VT} = \frac{7,5\ N.r}{x - 1,6}$$

We therefore get the supply capacity ratio between VT- and PD-fuzed
rounds:

$$\frac{SC_{VT}}{SC_{PD}} = r \cdot \frac{x - 2,4}{x - 1,6}$$

where x is assumed greater than 2,4 kilometres. We may deduce from
the formula for the supply capacity ratio, that in order to make
this value greater than 1, even with a low r-value of 2,0, it is
profitable from the supply point of view to use VT-fuze as soon
as x exceeds 3,2 kilometres, i.e. for very short carrying distances.

6.15 Operational analytic conclusions

Against lying personnel, either on the surface or in
trenches, the VT-fuze is superior to the PD-fuze. Under snow-
conditions this superiority is expected to be greatly increased.

Against standing personell on an ideal flat surface the
PD-fuze would appear to be superior. But the shadowing effects
of even very small obstacles on the surface or of snow will
probably very often reduce or reverse this superiority. New
experiments are necessary to determine when the reduction is so
great that it makes use of VT-fuze profitable.

From the tactical point of view, the VT-fuze is
superior as soon as the advantage ratio r and the supply capacity
ratio exceed 1. In these cases, both a greater intensity of fire,
as well as a greater amount of destruction can be obtained than is

possible with PD-fuzed shells. In these situations, the VT-
fuzed shells may be said to represent "lighter" and more effective
fire-power", an important fact when the necessity and the diffi-
culties of transport outside roads are taken into account.

From the strictly economic point of view, it is de-
sirable that the advantage ratio r exceeds the cost ratio of 4,5.
From the foregoing, it is obvious that this will happen in many
cases; against entrenched personnel as well as against personnel
lying on the surface of uneven ground or in snow.

When r is less than 1, the VT-fuze is of course of no
interest. In the situations when r lies between 1 and 4,5, the
tactical and the economic points of view differ, and the military
commander in question will have to make the decision.

6.2   Background philosophy and status of the NDRE-fuze

As has been described earlier in this report the NDRE-
fuze has now practically passed the development period, although
the last firing test showed some negative results. However,
reasonable scaled field tests will in all cases be necessary in
order to make a wellfounded evaluation of the fuze model.

A series of 50 fuzes is in an advanced state of pro-
duction, but a pilot production of 1000 fuzes is regarded as
necessary for full field testing.

It may be of interest to review briefly the philosophy
behind our fuze design. The main points may be summarized as
follows:

    a) Since the NDRE had very little experience with
       fuze design, we felt that our general approach
       would have to be fairly straight forward (if
       this term may be used in connection with
       Proximity fuzes).

    b) The NDRE could not afford to employ more than
       appx 7 workers on the project, and the techni-
       cal approach would have to take this into
       account.

    c) A production model ought to be ready within
       appx 3 years.

d) The fuze would have to be designed as
far as possible of Norwegian raw
materials and it should be adapted to
production within Norway. The situ-
ation within the Norwegian electronic
and mechanical industry should be born
in mind.

With these factors as guiding principles, our
line of approach will be easily understood and appreciated.
The only power unit practical was a wind driven generator
with magnetic material from the only Norwegian factory
producing Alnico alloys, the electronics practicable was
a combination of etched foil technique with dip soldering
and potting, our effort in the field of plastic moulding
had to be in accordance with the state of the art in
Norway etc.

Our result should therefore be viewed with
these factors as background.

We are, however, fully aware of the fact
that application of a wind driven generator as power source
has made the fuze more expensive in production and
electronically more complex than desired. Likewise the
generator is inherently more exposed against f ex salt
water. The reduction in firing range may however fairly
easy be overcome.

It remains however that the wind turbine as a
power source is a very reliable one and its substitution
with a battery source, for this non rotating mortar shell,
would no doubt introduce new problems which may be just
as serious and in all cases require a considerable research
and development effort. The arming arrangements with the
wind driven generator are very simple and reliable.

However, as will be clear from the operational analysis, in spite of these disadvantages our design will provide the infantry with a weapon under many (most) tactical situations far superior to the present weapon. Over snow covered ground, accurate data lacking, it is felt that the advantage ratio will be very considerable (see section 2.43 above)

There is no doubt that our fuze is not only tactical but also economically superior. The problem which requires more experiments is what percentage of all ammunition should be fuzed with VT-fuzes. Further it should be remembered that the ideal weapon is always too late.

The NKRM strongly recommends a pilot production of 1000 rounds for field testing. This will give us data and experience highly valuable for future fuze work.

6.3 Probable future activity on mortar fuzes

No doubt, there is always a long step in research, development and time between the actual weapon and the ideal one. Probably, the future VT-fuze for 81 mm mortar projectiles will be greatly reduced in weight and volume, and will show the same ballistic data as the PD-fuze. This will not be possible without a drastic simplification of the construction. If the turbine-generator power supply with its rectifier and filtering might be superseded by some sort of reserve battery, being activated during firing and able to withstand at least 25 years of storage, weight and volume would decrease. Besides, with the application of printed circuits as well as printed components and possibly transistorizing the R.F. and the A.F. parts of the fuze, this would make it compatible to the PD-fuze as regards ballistic data (shape and weight).

In Norway such development would require many years' work.

6.4 Acknowledgments

During the constructional and developmental work carried out on this project, many of our colleagues have been involved.

The main development has been undertaken by the special "P-fuze-group", at our Division for Telecommunication. This group has shown a very good example of team-work, the same personnel often being employed at the drawing-desk, in the workshop, in the plastic laboratory as well as behind the mortar during field tests. In addition, our different workshops have contributed to a great extent to the results of this project. A project of this type, with tests of destructive nature, will naturally depend very much on the workshop facilities.

As regards the explosive development carried out in connection with the project, acknowledgment is given to our Division for Explosives, with Mr. E. Strömsöe in charge of the P-fuze explosive train   Skill and everlasting patience has been shown during all experiments.

Acknowledgment is also given to Mr. K. Nygaard of our Division for Physics, who has considered the NDRE-fuze from an operational analytic point of view.

Lastly the support from the MWDT is gratefully acknowledged. The financial support has enabled us to increase our speed of development and the visits by the Team itself and the arranged visits of US experts have been most stimulating.

References

(1)   Firing tables for the M43A1 projectile. Dept. of the Army, FT81 B-3

(2) Larsen, Ø   Measurements of ground reflection coefficients. Technical Note, Div. T July 1956.

(3) Ordnance Dev't Division   The air burst proximity fuze for bombs, rockets and mortars. N.B.S. 1945, Div. 4-211-M3.

(4) Granstrøm, S.A.   Något om luftstøtsvågsbelastninger. Tidsskrift i fortifikasjon, 75, 173, 1952.

(5)   Ballistic data performance of ammunition. Dept. of the Army, TM9-1907

(6) Clemedson, C.J.   An experimental study on air blast injuries. Acta Physiol. Scand, 18, Supplementum LXI

(7)   ISA-tolerances and -fittings. (NS703) Norwegian Standardization Ass., Oslo 1944 - 1948.

(8) Larsen, Ø.   Influence of component tolerances on fuze sensitivity dispersion. Technical Note, Div. T, Dec. 1956.

(9) Stadeln, A.G.   Manufacture of Initiating Explosives at Wolfrathausen. CIOS Item No. 2 File No XXVII-38.

(10) Anderson, T.W.   Staircase methods of Sensitivity
     McCarthey, P.J.   Testing. NAVORD report No. 65-46
     Tukey, J.W.   PB-36952.

(11)   Preliminary fuze tests. NATO document AC/72-D/37 August 1956.

(12) Baxter, J.Ph.   Scientists against time. Little, Brown & Co., Boston 1948.

(13)   Infanterinytt No. 1, 1951.

In addition to the normal text references, the following reports and technical notes have been prepared during the development period of this project:

A PROGRESS REPORTS

Oct. 1953	A. Rambøl	III quarter 1953
Jan. 1954	A. Rambøl	IV quarter 1953
Apr. 1954	A. Rambøl	I quarter 1954
July 1954	Chr. Holm	II quarter 1954
July 1954	Chr. Holm	MWP status and progress report, 31/5-30/6-54.
Dec. 1954	F. Lied	Semi-annual report -31/12-54.
July 1955	F. Lied	Semi-annual report -30/6-55.
Dec. 1955	F. Lied	Semi-annual report -31/12-55.
June 1956	F. Lied	Semi-annual report -30/6-56.

B FIELD TEST REPORTS

Oct. 1953	A. Rambøl	Firing test Terningmoen 19/10.
June 1954	Chr. Holm	Drop tests with turbine-generator 8/6.
Feb. 1955	Chr. Holm	Drop tests with generator-equipped bombs 17/2.
Apr. 1955	Chr. Holm	Firing tests Terningmoen 29/3
May 1955	Chr. Holm Ø. Larsen	Firing tests Hurdalssjøen, 27/4 and 28/4.
June 1955	Chr. Holm Ø. Larsen	Firing tests, Horten 27/6
Sept 1955	Chr. Holm	Firing tests Horten 5/9.
Sept 1955	Chr. Holm	Firing tests Horten 14/9.
Sept 1955	Chr. Holm	Firing tests Horten 29/9.
Oct. 1955	Chr. Holm	Firing tests Horten 17/10.
Feb. 1956	Chr. Holm	Firing tests Stavern 16/2.
Apr. 1956	Chr. Holm	Firing tests Stavern 27/3.
July 1956	Ø. Larsen	Firing tests Horten 12/7.
Oct. 1956	Chr. Holm	Firing tests Horten 4/10.
Dec. 1956	Chr. Holm	Firing tests Horten 17/12.

C COMPONENTS, SUB-UNIT TESTING

May 1953	E. Ekeberg	Experimental studies of Hivac's thyratron XFG1 (I.R. No. T-72)
Oct. 1953	K. Berghoim A. Rambøl	DN69 as a firing tube. (I.R. No. T-82)
Dec. 1953	Chr. Holm E. Skogen	Alternating current heating of filamentory submin. tubes. (I.R. No. T-85)
Mar. 1956	Chr. Holm	Visit to England Feb. 1956 (subminiaturization)
Mar. 1956	J.V. Garwick	A problem in connection with electrical initiation of explosives (I.R. No. F-230)
Aug. 1954	M. Eggestad	Calibrations of Bump-Machine. (I.R. No. T-95)

Mar. 1955	R. Nordheim	Production of printed circuits by cold pressure welding of silver powder on an insulating support (I.R. No. K-115/55)
May 1955	M. Eggestad	On the magnetization and stabilization of 8-pole magnets. (I.R. No. T-102)
May 1955	A. Stav	Recording camera for 81 mm mortar shell.
Dec. 1955	M. Eggestad	Acceleration measurements of the 81 mm mortar projectile. (I.R. No. T-118)
Feb. 1956	M. Eggestad	DN69 subminiature thyratron as a firing tube.
Feb. 1956	M. Eggestad	Visit to Stavanger (ring magnets), 9/1.
Apr. 1956	Ø. Larsen	Durability of oscillator tube DC69.
May 1956	Ø. Larsen	Measurements of antenna impedance and radiated power from a mortar fuze.
June 1956	E. Strømsøe	Fragmentation from 81 mm mortar shell (I.R. No. X-38)
Sept. 1956	Ø. Larsen	Measurements of reflection coefficients of terrain.
Oct. 1956	M. Eggestad	Construction and calibration of shock testing apparatus.
Oct. 1956	M. Eggestad	Accelerations and muzzle velocities for 81 mm mortar projectile (I.R. No. T-118)
Nov. 1956	Chr. Holm	Visit to England 19-21/11. (Ring capacitors)
Dec. 1956	Chr. Holm	Theoretical and tactical considerations by fuzing 81 mm mortar projectiles with VT-fuzes. (I.R. No. T-139)