FFI-rapport 2015/02180

# Intermediate Scale Gap Test MCX-6100 CH 6027/14

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## English summary

The main explosive filling in munitions must have properties that fulfil the IM requirements in STANAG 4439 (1). An important property for several of the IM threats is the shock sensitivity of the explosive filling. Based on this, the Chemring composition MCX-6100 containing NTO/DNAN/RDX (53/32/15) have been tested for shock sensitivity in Intermediate Scale Gap Test according to STANAG 4488 Ed 2 (2). MCX-6100 is a melt-cast composition. The density difference between melted and solid material is significant, resulting in challenges in obtaining a high quality of the fillings. Tested gap test tubes had an average filling density of 1.726 g/$cm^3$ or 97.9 % of TMD (Theoretical Maximum Density). X-ray of the tubes showed good filling homogeneity in the bottom with a concentration of the pores and voids in the upper part of the tubes.

This series was tested by initiation from the top. Earlier, one series was tested by initiation from the bottom giving low shock sensitivity at 58.5 kbar.

For this series we obtained 36.4 kbar indicating that MCX-6100 initiated from the top has significant higher shock sensitivity than initiating from the bottom.

## Sammendrag

For at stridshoder skal tilfredsstille Insensitive Munitions-kravene (IM) gitt i STANAG 4439 (1), må hovedsprengstoffet ha egenskaper som passer til dette kravet. En viktig egenskap for å motstå flere av IM-truslene er sjokkfølsomheten til sprengstoffyllingen. Med denne bakgrunnen har Chemring-komposisjonen MCX-6100 med sammensetning NTO/DNAN/RDX (53/32/15) vært testet for sjokkfølsomhet i Intermediate Scale Gap Test i henhold til STANAG 4488 Ed 2 (2). MCX-6100 er en smelt-støp komposisjon. Forskjellen i tetthet mellom flytende og fast masse er stor, noe som gir store utfordringer med å oppnå god kvalitet/tetthet på støpte fyllinger. For de gaptest-rørene som har vært testet, har MCX-6100-sprengstoffyllingen i gjennomsnitt en tetthet på 1.726 g/cm$^3$ eller 97.9 % av TMD (Theoretical Maximum Density). Røntgen av rørene viser gjennomgående en god homogenitet for nedre halvdel av fyllingene, mens ansamling av porer og tomrom er konsentrert i øvre del av rørene.

Resultat for MCX-6100 med 50 % sannsynlighet for initiering var 36.4 kbar. Dette er en svært moderat sjokkfølsomhet sammenlignet med resultat ved initiering fra bunnen, 58.5 kbar. Imidlertid viser de samlede resultatene at MCX-6100 er en komposisjon med stort potensiale for å oppnå gode IM-egenskaper for systemer hvor dette inngår.

# Contents

## Abbreviations

| | |
|---|---|
| BAMO | 3,3-Bis-azidomethyl oxetane |
| DNAN | 2,4-dinitroanisole |
| DSTO | Defence Science and Technology Organization |
| GA | Glycidyl azide |
| GA/BAMO | Glycidyl azide- (3,3-bis(azidomethyl)oxetane) Copolymers |
| HMX | Octogen/1,3,5,7-tetranitro-1,3,5,7-tetraazacyclooctane |
| HWC | Hexogen/Wax/Graphite (94.5/4.5/1) |
| IM | Insensitive Munitions |
| IMX-104 | NTO/DNAN/RDX (53/31.7/15.3) (3) |
| MCX | Melt Cast Explosive |
| MCX-6100 | NTO/DNAN/RDX (53/32/15) |
| NTO | 3-Nitro-1,2,4 Triazol 5-one |
| RDX | hexogen/1,3,5 -trinitro-1,3,5-triazacyclohexane |
| TMD | Theoretical Maximum Density |
| TNT | 2,4,6-trinitrotoluene |
| WP | Work Package |

# 1 Introduction

Under the EDA project arrangement No B-0585-GEM2-GC "Formulation and Production of New Energetic Materials" different melt-cast compositions in addition to compositions containing GA/BAMO polymers have been studied. Norway had their main activity in the synthesis of GA/BAMO polymers suitable for coating nitramines for production of press granules, for press filling of munitions or production of pressed charges.

Norway was the only country that used the energetic binder for explosive charges. Italy and Germany used their polymers as binders for propellants. The produced compositions had a high content of HMX (94-97 wt%). Their primary application will be as boosters or main fillings for shaped charges.

In order to broaden the number of compositions in the generic fragmentation testing in 40 mm shells in WP 4000, Norway included 4 melt cast compositions. These compositions are of interest for Norway as main filler preferential for large caliber munitions. Two compositions have TNT and two have DNAN as binder, while the filler is NTO/RDX or NTO/HMX. These compositions have, in addition to fragmentation performance, been characterized for the most important properties as detonation velocity, detonation pressure and critical diameter.

Dinitroanisole (DNAN) is a key IM melt-phase ingredient that is currently featured in several IM melt-pour formulations developed by the U.S. Army and the Australians DSTO (Defence Science and Technology Organization) (3-7). Current interest in DNAN has arisen due primarily to its ability to provide a less sensitive melt-cast medium than TNT and allows for the development of less sensitive melt-cast formulations. Since DNAN is processed essentially the same way as TNT, analogous explosive formulations can easily be transitioned. In addition, DNAN can be demilitarized in the same way as TNT using the same recovery / re-use hardware. Currently DNAN-based formulations are tailored to have TNT or Comp B performance, while having decreased sensitivity.

In this report one of the studied compositions, MCX-6100 has been tested with regard to shock sensitivity. MCX-6100 contains DNAN as binder and NTO/RDX as filler. Nominal content is 32/53/15 (DNAN/NTO/RDX). This composition has NTO/RDX content in the same range as the DNAN based US composition IMX-104 and the TNT based Chemring composition MCX-6002 (9). We have earlier tested the same composition in Intermediate Scale Gap Test with a result of 58.5 kbar (8). In that test the tubes were initiated from the bottom. X-ray of the tubes shown highest concentration of bubbles and low density areas in the top of the tubes. However, the lower part of the tubes had few inclusions. In addition to inclusions some sedimentation may occur during casting. Therefor this series was tested by initiation from the top of the tubes to obtain the best and worst case of sensitivity.

The shock sensitivity was determined by use of the Intermediate Scale Gap Test according to STANAG 4488 (2). The shock sensitivity of a composition is important from two different viewpoints. To be able to design a reliable initiation train it's necessary to know the pressure needed for initiation. On the other side, to be able to protect the munitions against external threats the shock sensitivity is one of the most important properties of an explosive filling. The responses from threats like Bullet Impact, Fragment Impact, Sympathetic Detonation and Shaped Charge Jet depends upon shock properties of the acceptor. The IM requirements given by STANAG 4439 (1) are easier achieved with main explosive fillings having low shock sensitivity.

# 2 Experimentally

## 2.1 Tube dimensions

The used tubes were mainly produced and measured by Nammo Raufoss. Table 2.1 summaries the measured dimensions and weights for the tubes. For tubes 21 and 22 from FFI only the weight was measured before they were filled with MCX-6100 CH 6027/14.

| Tube No | Weight (g) | Height (mm) | Inner Diameter (mm) | | | | Radius (mm) | Volume ($cm^3$) |
|---|---|---|---|---|---|---|---|---|
| | | | $190^o$ | $100^o$ | $10^o$ | Average | | |
| **1** | 860.51 | 200.344 | 40.045 | 40.095 | 40.036 | 40.06 | 20.03 | **252.50** |
| **2** | 864.73 | 200.228 | 40.04 | 40.076 | 39.959 | 40.03 | 20.01 | **251.93** |
| **3** | 860.40 | 200.226 | 40.045 | 40.095 | 40.042 | 40.06 | 20.03 | **252.38** |
| **4** | 863.20 | 200.193 | 40.038 | 40.079 | 39.982 | 40.03 | 20.02 | **251.99** |
| **5** | 860.10 | 200.183 | 40.038 | 40.099 | 40.045 | 40.06 | 20.03 | **252.32** |
| **6** | 860.07 | 200.195 | 40.038 | 40.097 | 40.047 | 40.06 | 20.03 | **252.34** |
| **8** | 860.15 | 200.224 | 40.044 | 39.967 | 40.049 | 40.02 | 20.01 | **251.86** |
| **9** | 860.46 | 200.213 | 40.038 | 40.000 | 40.041 | 40.03 | 20.01 | **251.93** |
| **10** | 858.80 | 200.219 | 40.044 | 39.973 | 40.098 | 40.04 | 20.02 | **252.09** |
| **11** | 860.34 | 200.228 | 40.039 | 40.016 | 40.049 | 40.03 | 20.02 | **252.05** |
| **21** | 884.80 | | | | | | | |
| **22** | 885.20 | | | | | | | |

*Table 2.1 Measured dimensions and weights for gap test tubes used in testing of MCX-6100 CH 6027/14 in Intermediate Scale Gap Test.*

## 2.2 Casting – tube filling

Filling of the gap test tubes were performed by Chemring Nobel at Sætre. Figure 2.1 and 2.2 shows pictures of the tubes after filling as received them at FFI.

*Figure 2.1 Picture of tubes No 1 to No 9 as received from Chemring Nobel AS.*


*Figure 2.2 Picture of tubes No 6 to No 22 as received from Chemring Nobel AS.*

Adjustment of the filling level for both ends and cleaning of the tubes were performed at FFI. Most of the fillings in the tubes manufactured at Nammo Raufoss, which had a smooth inner surface, had fillings that were loose and could be taken out of the tubes.

*Figure 2.3    The figure shows pictures of the top of tubes No 1 to No 6.*

*Figure 2.4    The figure shows pictures of the bottom of tubes No 1 to No 6.*

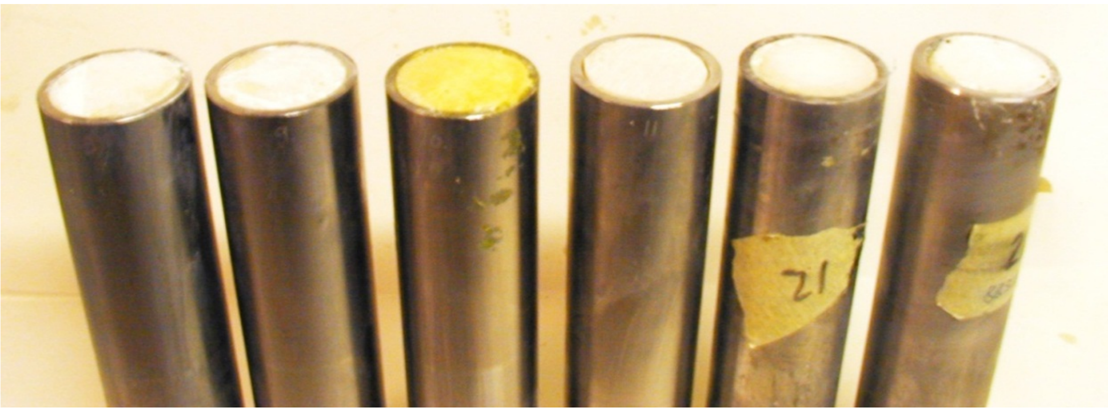


*Figure 2.5    The figure shows pictures of the top of tubes No 8 to No 22.*


*Figure 2.6 The figure shows pictures of the bottom of tubes No 8 to No 22.*

### 2.3 X-ray

All filled tubes were X-rayed at Nammo Raufoss before testing. The X-ray pictures indicate high porosity in the upper half of the tubes. For some of the tubes even empty spaces are observed. In Figure 2.7 and Figure 2.8 this is observed for tube No 2 and tube No 3.

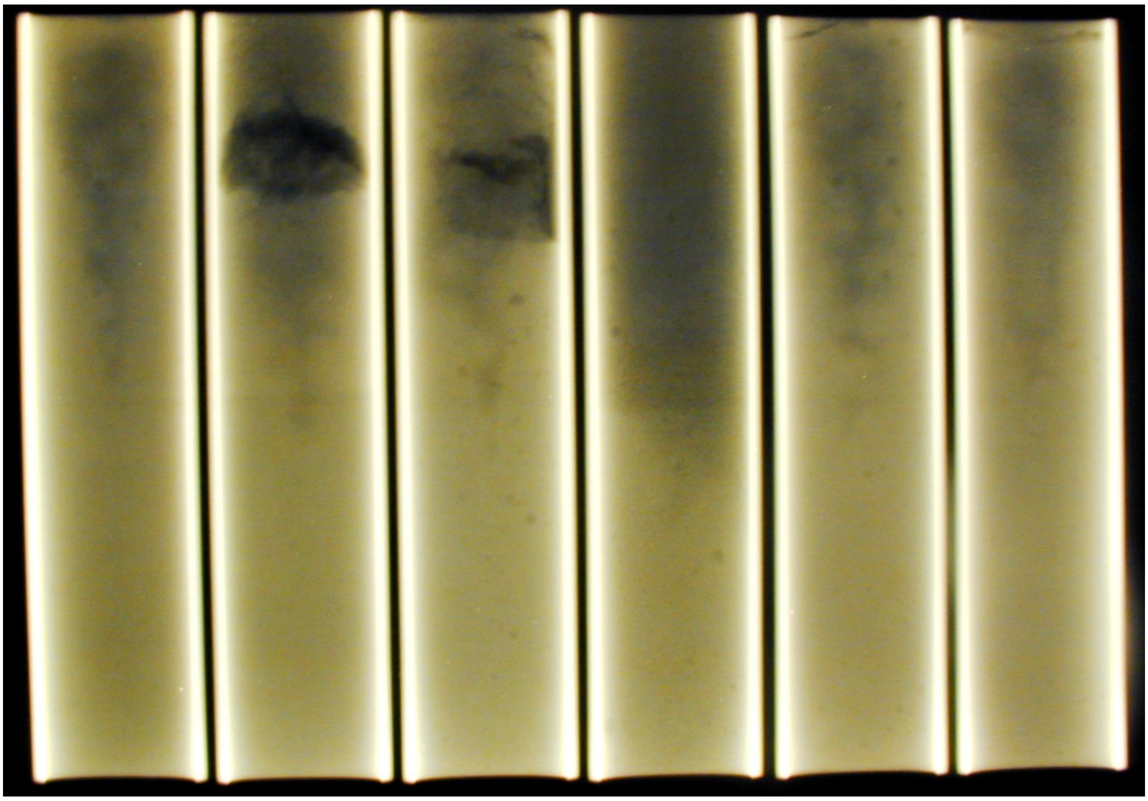

*Figure 2.7 The figure shows the X-ray picture of tubes No 1 to No 6 at 90$^o$.*

*Figure 2.8 The figure shows the X-ray picture of tubes No 1 to No 6 at 0°.*

Tube No 4 as Figures 2.7 and 2.8 shows is very dark in the top indicating very low density. This observation confirmed the overall density of 1.5 $g/cm^3$ of the filling in Table 3.1.

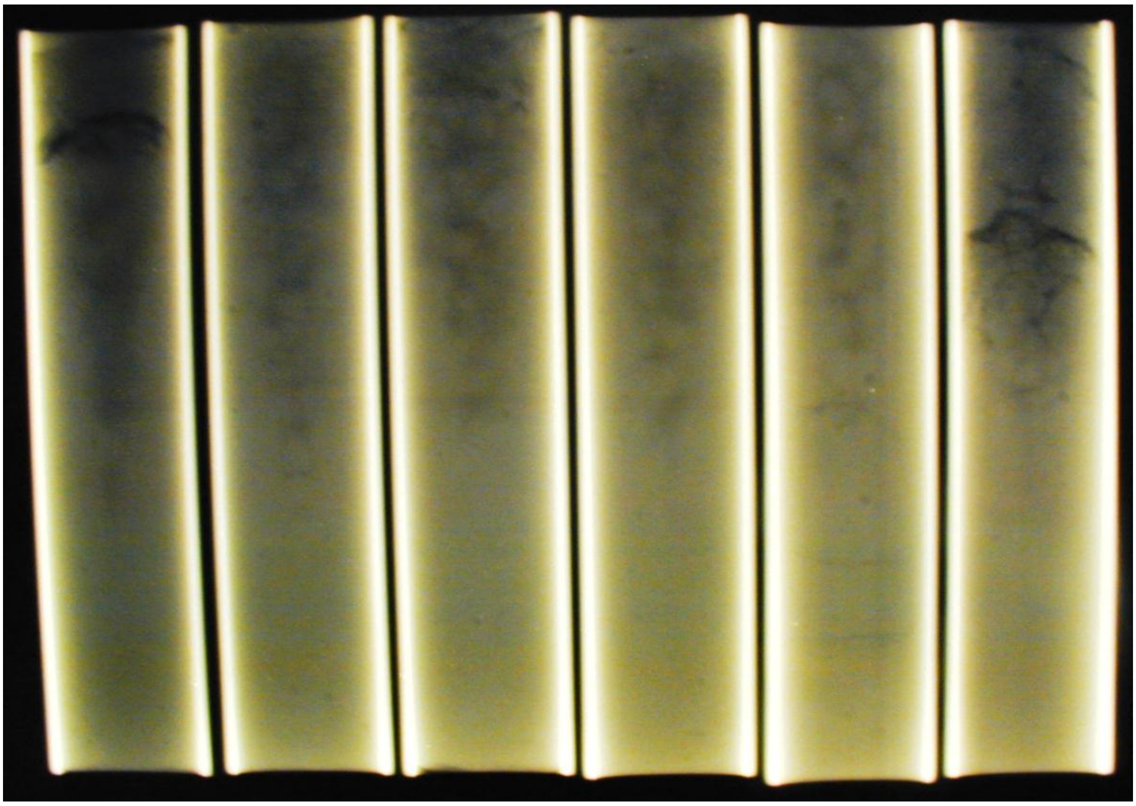

*Figure 2.9 The figure shows the X-ray picture of tubes No 8 to No 22 at 90°.*

*Figure 2.10 The figure shows the X-ray picture of tubes No 8 to No 22 at 0°.*

Tubes 21 and 22 had not modified inner surface. The fillings in these tubes have bonding to the surface. However, by a closer look on the X-ray pictures in Figure 2.11, it looks like the lower part of the fillings has some cracks. Cracks are not observed for the loose fillings, where there is no bonding to the tube surface.

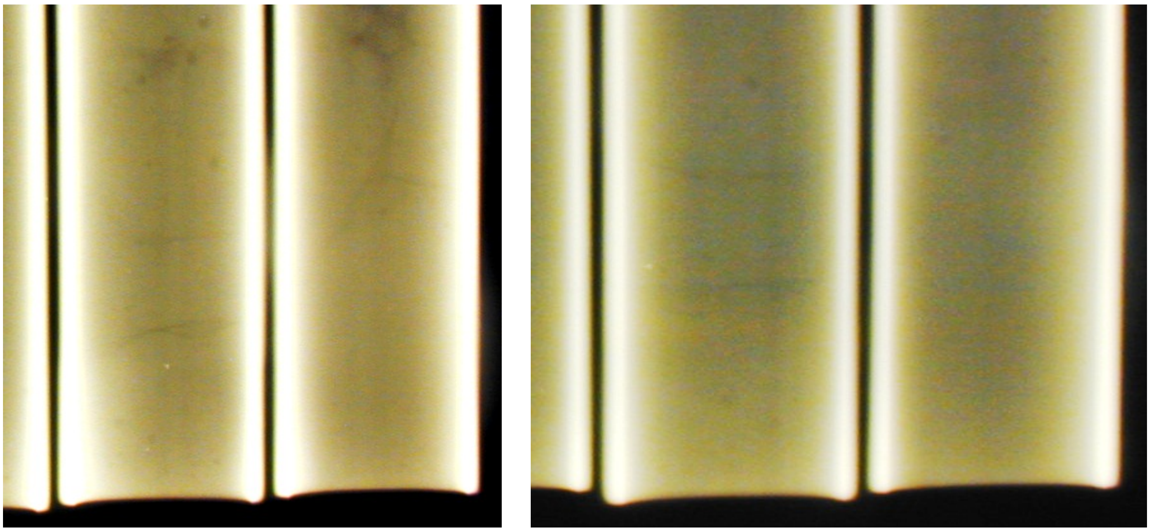

*Figure 2.11 The figure shows magnified X-ray pictures of tube 21 and tube 22, left at 0° and right at 90°.*

## 2.4 Intermediate Scale Gap Test

We have used the Intermediate Scale Gap Test described in STANAG 4488 (2) for determination of the shock sensitivity with on waiver. The cards we used had a thickness of 0.254 mm instead of 0.19+0.002/-0.001 mm recommended in STANAG 4488.

As booster explosive we used HWC containing RDX/Wax/Graphite (94.5/4.5/1). The booster was pressed with 7.2 tons pressure and a dwell time of 60 seconds. The control report for the booster explosive is given in Appendix A. The booster pellets with hole for the detonator were pressed by Nammo Raufoss. A detonator No 8 was used to initiate the booster. Figure 2.12 shows the test conditions for the firings.

*Figure 2.12 The picture shows the test setup for firing of the gap test tubes.*

# 3 Results

## 3.1 Properties of filled tubes

TMD for MCX-6100 nominal content is 1.7629 g/cm$^3$. Table 3.1 gives properties of the filled tubes.

| MCX 6100 CH 6027/14 | | | | | |
|---|---|---|---|---|---|
| Tube No | Weight Tube (g) | | Weight filling (g) | Volume Tube (cm$^3$)[a] | Filling density (g/cm$^3$) |
| | Filled | Empty | | | |
| **1** | 1285.95 | 860.51 | 425.44* | 244.99 | **1.737** |
| **2** | 1260.30 | 864.73 | 395.57* | 244.43 | **1.618** |
| **3** | 1263.8 | 860.40 | 403.40 | 244.87 | **1.647** |
| **4[b]** | 1230.83 | 863.20 | 367.63 | 244.49 | **1.504** |
| **5** | 1279.92 | 860.10 | 419.82 | 244.82 | **1.715** |
| **6** | 1281.74 | 860.07 | 421.67* | 244.83 | **1.722** |
| **8** | 1272.72 | 860.15 | 412.57* | 244.37 | **1.688** |
| **9** | 1283.47 | 860.46 | 423.01* | 244.43 | **1.731** |
| **10** | 1277.27 | 858.80 | 418.47 | 244.59 | **1.711** |
| **11** | 1287.58 | 860.34 | 427.24* | 244.55 | **1.747** |
| **21** | 1306.58 | 884.80 | 421.78 | 245.00[c] | **1.722** |
| **22** | 1280.45 | 885.20 | 395.25 | 245.00[c] | **1.613** |

**[a]Most tubes had loose fillings. The diameter of the fillings has been reduced by 0.06 cm.**
**[b]Wrong casting procedure.**
**[c] Volume estimated from weights and measured volumes for a large number of tubes.**
**[*]Weight of the filling outside the tube.**

*Table 3.1 Properties of gap tubes filled with MCX-6100 CH 6027/14.*

The density of the fillings can be divided into two groups. For tubes No 2 - 4, No 8 and No 22 the X-ray shows empty spaces or large areas of low density. This explains the low density of these fillings. The remaining 7 tubes have no visual empty areas, and the fillings have an average density of $\rho$ = 1.726 g/cm$^3$ or 97.9 % of TMD. For these tubes the density of the fillings is as expected when casting have been performed with no vacuum.

## 3.2 Firings

Although the quality of the filling did vary significantly, the firing of the tubes was in the order of filling, except for tube No 4 having very low density. Tube No 4 was fired as the last one. All tubes were initiated from the top. Earlier we performed a test series of MCX-6100 by initiation from the bottom (8).

### 3.2.1 Firing No 1

We started the testing by firing tube No 1 with a barrier thickness of 110 cards. Figure 3.1 shows the response with a witness plate having a hole from a detonation response of the test tube.

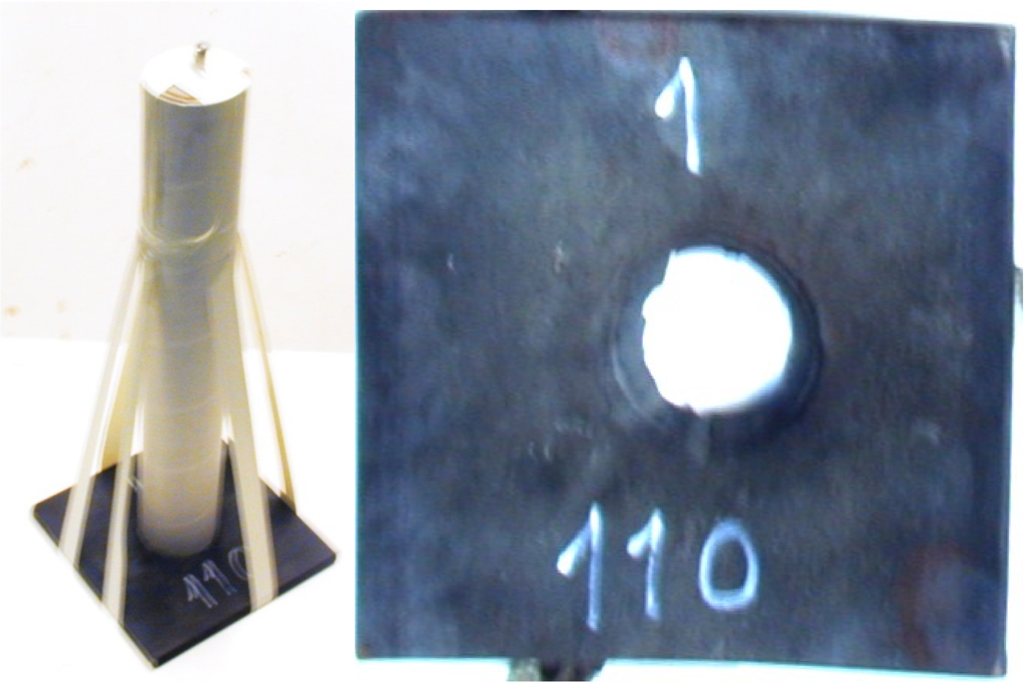


*Figure 3.1 Firing No 1, tube No 1, barrier thickness 110 cards. Response: Detonation.*

### 3.2.2 Firing No 2

For firing No 2 with tube No 2 the barrier thickness was increased to 120 cards. This did not change the response, which still was a detonation response. Figure 3.2 shows the recovered witness plate.

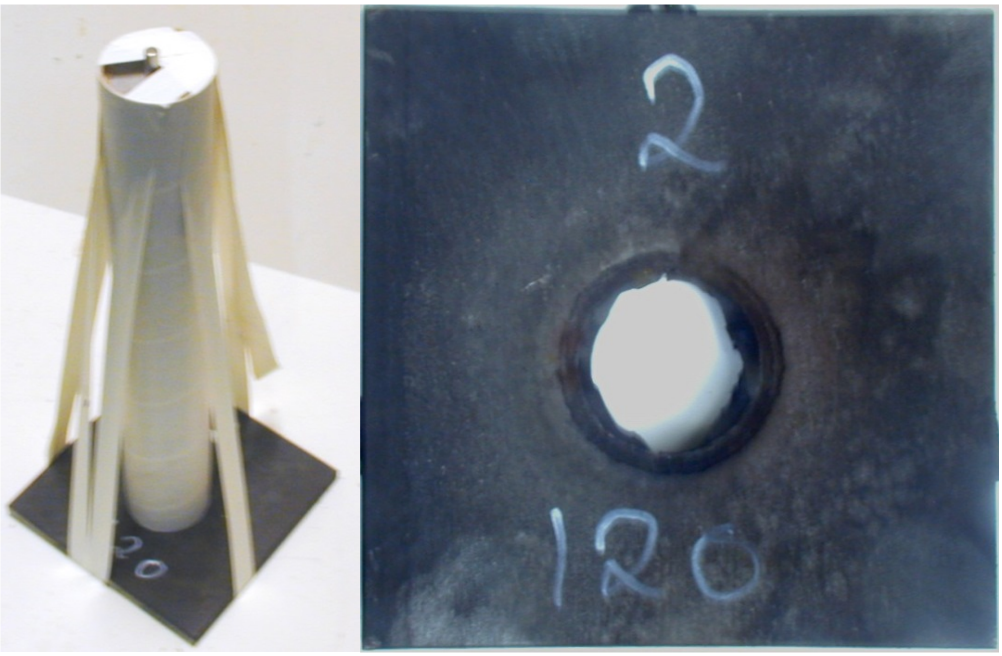


*Figure 3.2 Firing No 2, tube No 2, barrier thickness120 cards. Response: Detonation.*

### 3.2.3 Firing No 3

For firing No 3 with tube No 3 we increased the barrier thickness to 135 cards. This gave a no reaction response. Figure 3.3 shows the recovered tube fragments and a witness plate with no damage. 709 g of fragments of a 860 g tube was recovered.

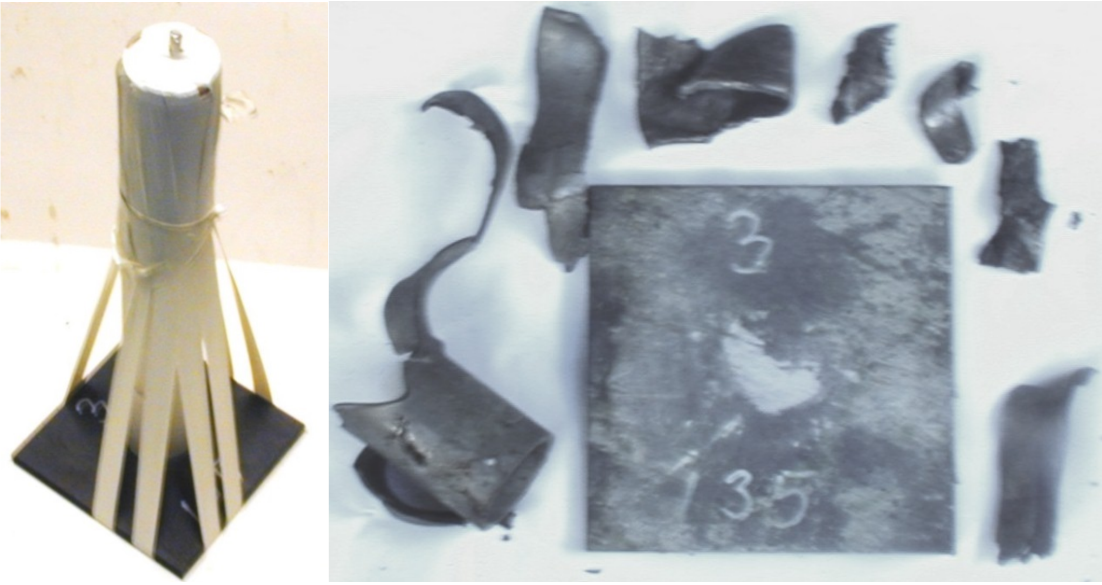


*Figure 3.3 Firing No 3, tube No 3, barrier thickness 135 cards. Response: No reaction. Recovered 709 g steel fragments from the tube body.*

### 3.2.4 Firing No 4

Firing No 4 was with tube No 5. The barrier thickness was reduced to 125 cards. This gave a detonation response. Figure 3.4 shows a picture of the test item before firing and of the recovered witness plate with a hole after firing.

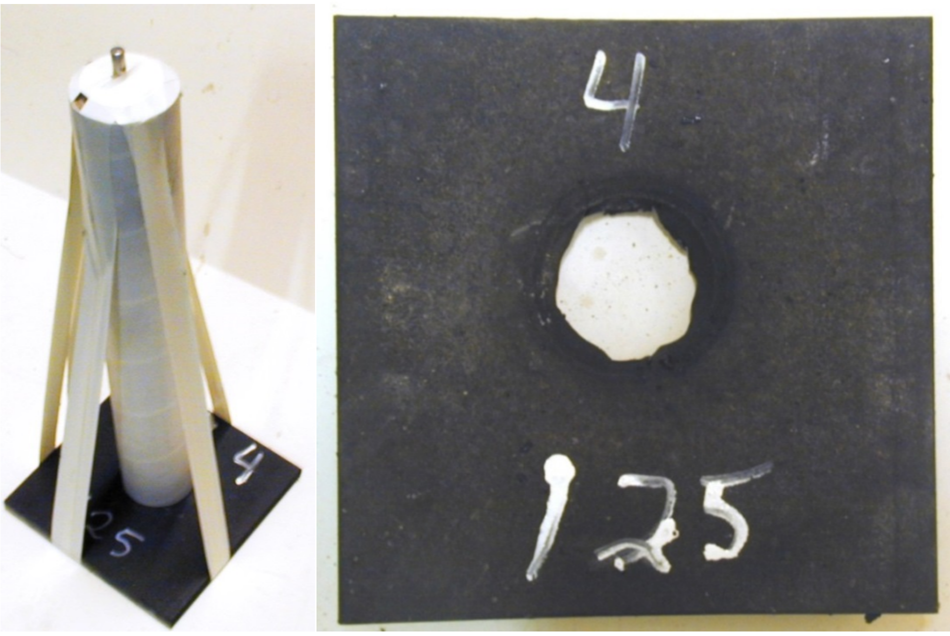


*Figure 3.4 Firing No 4, tube No 5, barrier thickness125 cards. Response: Detonation.*

### 3.2.5 Firing No 5

Firing No 5 of tube No 6 was performed with a barrier thickness of 130 cards. Figure 3.5 shows the test item before firing and the witness plate after firing. The witness plate had a hole, indicating a detonation response in the acceptor.

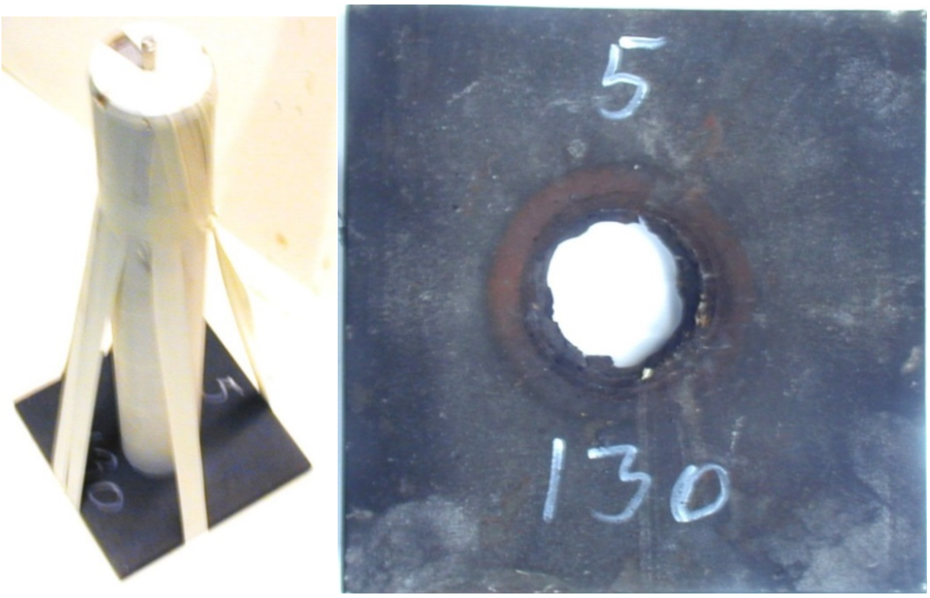


*Figure 3.5 Firing No 5, tube No 6, barrier thickness 130 cards. Response: Detonation.*

### 3.2.6 Firing No 6

Firing No 6 of tube No 7 was performed with a barrier thickness of 135 cards. Figure 3.6 shows the test item before firing and the witness plate after firing. The witness plate had a hole, indicating a detonation response in the acceptor.


*Figure 3.6 Firing No 6, tube No 8, barrier thickness135 cards. Response: Detonation.*

### 3.2.7 Firing No 7

Firing No 7 with tube No 9 had a barrier thickness of 140 cards. Figure 3.7 shows pictures of the test item before firing and of the witness plate and the remnant of the tube after firing. The weight of the recovered tube fragments was 847.57 g. The weight of the empty tube was 860.46 g, so most of the tube was recovered.

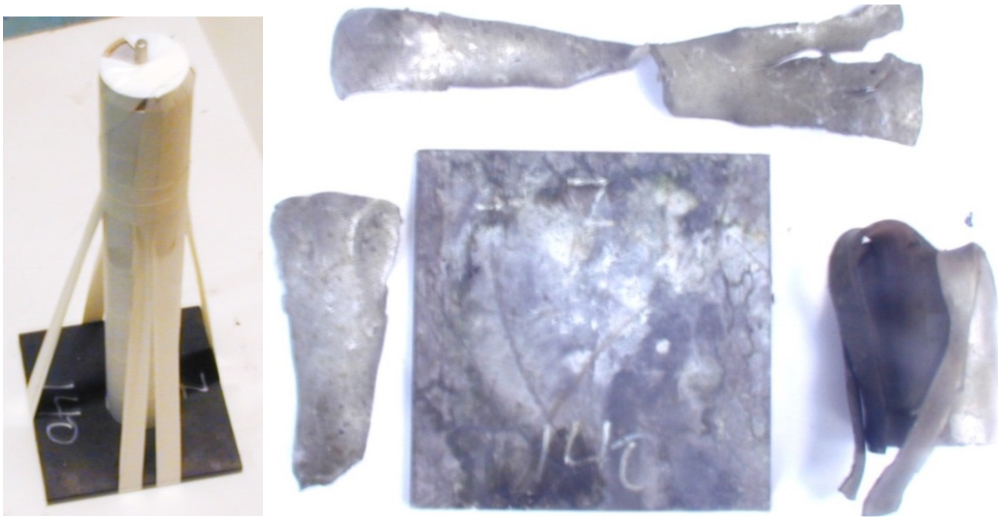

*Figure 3.7 Firing No 7, tube No 9, barrier thickness140 cards. Response: No reaction. Recovered fragment mass of tube 847.54 g.*

### 3.2.8 Firing No 8

Firing No 8 contained tube No 10. The barrier thickness was unchanged 140 cards. Figure 3.8 shows pictures of the test item before firing and the remnant recovered after firing.

*Figure 3.8 Firing No 8, tube No 10, barrier thickness140 cards. Response: No reaction. The weight of the recovered tube remnant is 694 g.*

The undamaged witness plate gives a no reaction response. The weight of the recovered tube body fragments was 694 g. The original weight of the tube was 858.8 g, indicating that some large fragments are missing.

### 3.2.9 Firing No 9

Firing No 9 contained tube No 11. The barrier thickness was reduced by 5 cards to 135 cards. Figure 3.9 shows pictures of the test item before firing and the remnant recovered after firing.


*Figure 3.9 Firing No 9, tube No 11, barrier thickness140 cards. Response: No reaction. The weight of the recovered tube remnant is 831.74 g.*

The undamaged witness plate shows a no reaction response. The weight of the recovered tube body fragments was 831.74 g. The original weight of the tube was 860.34 g, indicating that most of the fragment mass is recovered.

### 3.2.10 Firing No 10

Firing No 10 contained tube No 21. The barrier thickness was unchanged 135 cards. Figure 3.10 shows pictures of the test item before firing and the remnant recovered after firing. The undamaged witness plate shows a no reaction response. The weight of the recovered tube body fragments was 633 g. The steel weight of the tube was 884.8 g before filling, indicating that some large fragments are missing.


*Figure 3.10 Firing No 10, tube No 21. Barrier thickness: 135 cards. Response: No reaction. The weight of the recovered tube remnant is 633 g.*

### 3.2.11 Firing No 11

Firing No 11 contained tube No 22. The barrier thickness was reduced by 5 cards to 130 cards. Figure 3.11 shows pictures of the test item before firing and the remnant recovered after firing.

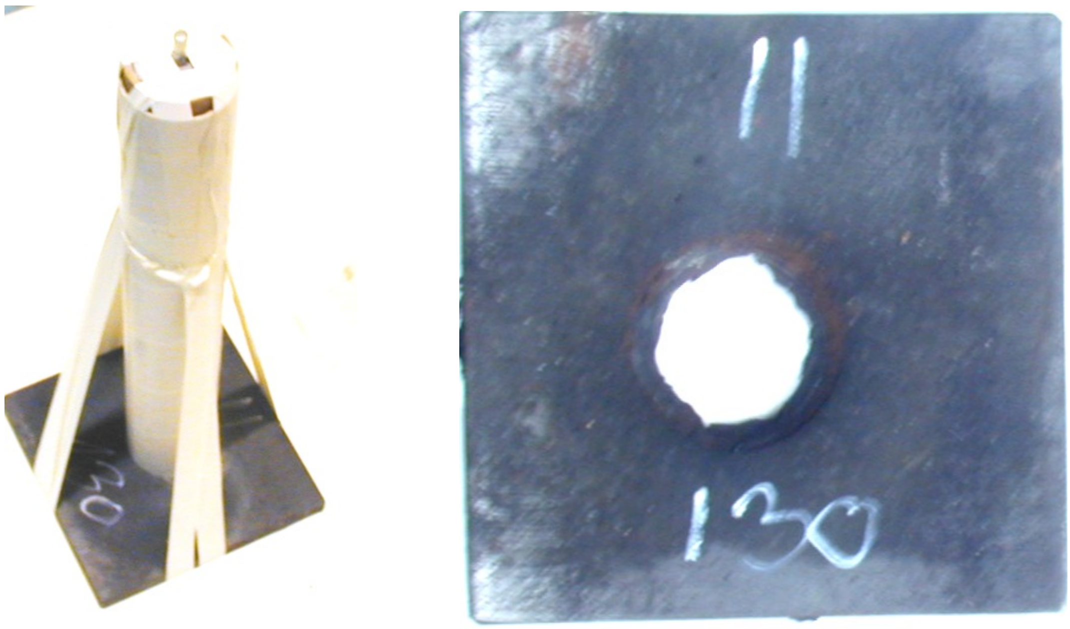


*Figure 3.11 Firing No 11, tube No 22. Barrier thickness: 130 cards. Response: Detonation.*

The witness plate has a hole indicating a detonation reaction response.

### 3.2.12 Firing No 12

Firing No 12 contained tube No 4 having a MCX-6100 filling with low density. The barrier thickness was increased by 5 cards to 135 cards. Figure 3.12 shows pictures of the test item before firing and the remnant recovered after firing. The witness plate has a hole indicating a detonation reaction response.

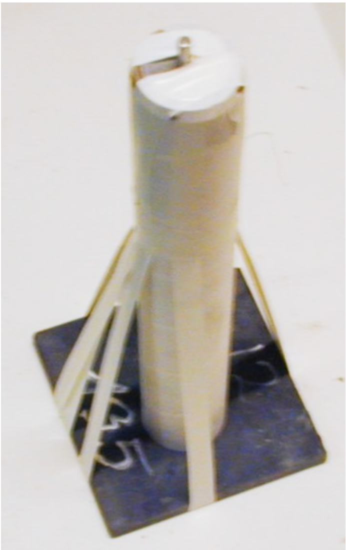


*Figure 3.12 Firing No 12, tube No 4. Barrier thickness: 135 cards. Response: Detonation.*

## 3.3 Summary of gap test results

Table 3.2 summaries the condition and results of all firings of gap test tubes filled with MCX-6100 CH 6027/14 composition. Figure 3.11 shows the same information as a diagram.

| Firing No | Tube No | Number of Cards | Barrier Thickness (mm) | Response |
|---|---|---|---|---|
| 1 | 1 | 110 | 29.94 | Detonation |
| 2 | 2 | 120 | 30.48 | Detonation |
| 3 | 3 | 135 | 34.29 | No reaction |
| 4 | 5 | 125 | 31.75 | Detonation |
| 5 | 6 | 130 | 33.02 | Detonation |
| 6 | 8 | 135 | 34.29 | Detonation |
| 7 | 9 | 140 | 35.56 | No reaction |
| 8 | 10 | 140 | 35.56 | No reaction |
| 9 | 11 | 140 | 35.56 | No reaction |
| 10 | 21 | 135 | 34.29 | No reaction |
| 11 | 22 | 130 | 33.02 | Detonation |
| 12 | 4 | 135 | 34.29 | Detonation |

*Table 3.2 Summary of the gap test firings with MCX-6100 CH 6027/14.*

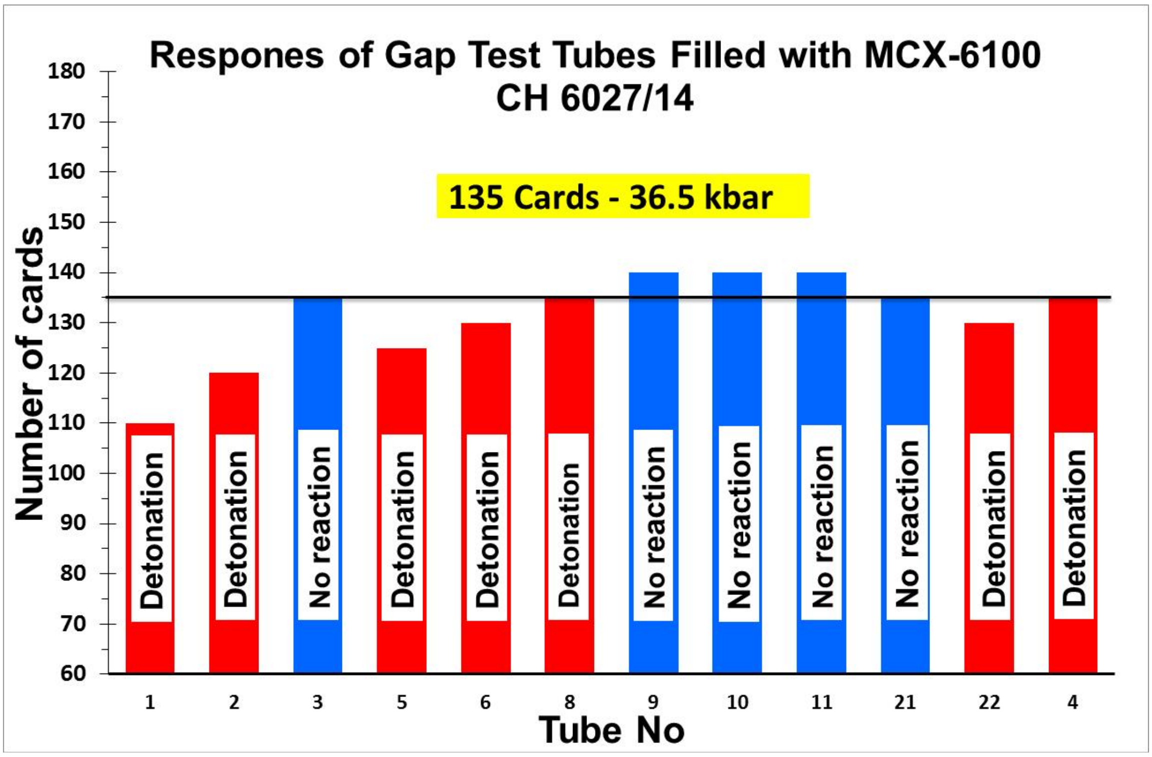


*Figure 3.13 Plot of the responses for each tested Intermediate Scale Gap Test tubes filled with MCX-6100 CH 6027/14 composition.*

From Figure 3.13 one will see, that the responses for the 4firings with barrier thickness 135 cards gives 2 with detonation response and 2 with no reaction response. For the 3 firings with thicker barrier, 140 cards, the response is a no reaction. The 5 firings with a thinner barrier, 130 cards or less, give all a detonation response. Our interpretation of the results is therefore, that 135 cards or 34.29 mm thick barrier gives the transition for 50% probability of obtaining a detonation response. According to Figure B.1 in Appendix B corresponds a barrier thickness of 34.29 mm to a pressure of **36.4 kbar.** This result is significant lower than for IMX-104 in the literature (3), and for MCX-6100 initiated from the bottom with 58.5 bars (8).

The not optimal density of the fillings seems to have influence on the shock sensitivity when we initiate the acceptor from the top. Most of the inclusions of air are in the upper half of the tube filling. Sedimentation due to density differences of the ingredients may results in higher content of NTO in the bottom of the tested tubes.

## 4 Summary

Melt-cast composition MCX-6100 has been filled into Intermediate Scale Gap Test tubes. Quality of the casted fillings was investigated by X-ray and density measurements. 12 tubes have been tested with different barrier thickness between donor and acceptor to determine the 50% probability for obtaining a detonation transition response. All test tubes were initiated from the top. Casted MCX-6100 CH 6027/14 initiated from the top needs a shock pressure of 36.4 kbar to respond with a detonation in Intermediate Scale Gap Test tubes.

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9. Gunnar Ove Nevstad: Intermediate Scale Gap Test of MCX-6002, FFI-rapport 2015/2184, 18 October.

# Appendix A Control report HWC

**KONTROLLRAPPORT B**
etter EN 10204 - 3.1

Chemring Nobel

| | | |
|---|---|---|
| Kjøper/Mottaker<br>FFI<br>Postboks 25<br>2007 Kjeller | Bestillingsnummer<br>V/ Gunnar Nevstad<br>Bestillingsdato<br>16.01.14 | Rapportnummer<br>045<br>Kontrolldato<br>27.01.14 |
| Produsent<br>Dyno Nobel ASA<br>N-3476 Sætre<br>NORWAY | Produksjonsdato<br>23.01.14 | Offentlig oppdragsnummer |
| Lot nummer<br>DDP14A0068-0002 | Mengde<br>10 kg | |
| Sprengstofftype<br>**RDX/VOKS/GRAFITT, 94,5/4,5/1** | Leveringsbetingelser/Teknisk underlag<br>For testing | |

Analyseresultater for loten

| | Sammensetning | | | Fuktighet og flyktige bestanddeler | Surhet | |
|---|---|---|---|---|---|---|
| | RDX | Voks | Grafitt | | | |
| KRAV | 94,5 ± 0,5 % | 4,5 ± 0,5 % | 1,0 ± 0,2 % | ≤ 0,1% | ≤ 0,02 % | |
| RESULTAT 03/14 | 94,4 | 4,7 | 0,9 | 0,0 | 0,00 | 0,0 |

| | Uløste partikler på USS No. 60 | Vacuum stabilitet | Volumvekt | Kornfordeling %, USS No. | | |
|---|---|---|---|---|---|---|
| | | | | > 12 | > 18 | < 100 |
| KRAV | Ingen | ≤ 1,2 ml/g | 0,86 - 0,93g/ml | 0 | ≤ 2 | ≤ 1 |
| RESULTAT 03/14 | ingen | 0,1 | 0,89 | 0 | 0 | 1 |

Kvalitetssjef

Chemring Nobel AS
High Energy Materials
Manager QA

*Figure A.1 Control report of the HWC used as donor explosive.*

## Appendix B Relation between barrier thickness and pressure

STANAG 4488 gives the relation between barrier thickness and pressure for HWC donors with density $\phi$=1.60 g/cm$^3$. The number of cards is different from what we have used since our card is thicker, 0.254 mm than those in Figure B.1.

ANNEX B to
STANAG 4488
(Edition 2)

TABLE 2. INTERMEDIATE SCALE GAP TEST CALIBRATION DATA
RDX/WAX/GRAPHITE DONOR

| # OF CARDS | BARRIER THICKNESS (mm) | PRESSURE (kbar) | # OF CARDS | BARRIER THICKNESS (mm) | PRESSURE (kbar) |
|---|---|---|---|---|---|
| 10 | 1.90 | 185.4 | 230 | 43.70 | 22.8 |
| 20 | 3.80 | 168.6 | 235 | 44.65 | 21.7 |
| 30 | 5.70 | 153.2 | 240 | 45.60 | 20.7 |
| 40 | 7.60 | 139.3 | 245 | 46.55 | 19.7 |
| 50 | 9.50 | 126.7 | 250 | 47.50 | 18.8 |
| 60 | 11.40 | 115.1 | 255 | 48.45 | 18.0 |
| 70 | 13.30 | 104.7 | 260 | 49.40 | 17.1 |
| 80 | 15.20 | 95.2 | 265 | 50.35 | 16.3 |
| 90 | 17.10 | 86.5 | 270 | 51.30 | 15.6 |
| 100 | 19.00 | 78.7 | 275 | 52.25 | 14.8 |
| 105 | 19.95 | 75.0 | 280 | 53.20 | 14.1 |
| 110 | 20.90 | 71.5 | 285 | 54.15 | 13.5 |
| 115 | 21.85 | 68.2 | 290 | 55.10 | 12.9 |
| 120 | 22.80 | 65.0 | 295 | 56.05 | 12.3 |
| 125 | 23.75 | 62.0 | 300 | 57.00 | 11.7 |
| 130 | 24.70 | 59.1 | 305 | 57.95 | 11.1 |
| 135 | 25.65 | 56.4 | 310 | 58.90 | 10.6 |
| 140 | 26.60 | 53.7 | 315 | 59.85 | 10.1 |
| 145 | 27.55 | 51.2 | 320 | 60.80 | 9.7 |
| 150 | 28.50 | 48.8 | 325 | 61.75 | 9.2 |
| 155 | 29.45 | 46.6 | 330 | 62.70 | 8.8 |
| 160 | 30.40 | 44.4 | 335 | 63.65 | 8.4 |
| 165 | 31.35 | 42.3 | 340 | 64.60 | 8.0 |
| 170 | 32.30 | 40.4 | 345 | 65.55 | 7.6 |
| 175 | 33.25 | 38.5 | 350 | 66.50 | 7.2 |
| 180 | 34.20 | 36.7 | 355 | 67.45 | 6.9 |
| 185 | 35.15 | 35.0 | 360 | 68.40 | 6.6 |
| 190 | 36.10 | 33.4 | 365 | 69.35 | 6.3 |
| 195 | 37.05 | 31.8 | 370 | 70.30 | 6.0 |
| 200 | 38.00 | 30.3 | 375 | 71.25 | 5.7 |
| 205 | 38.95 | 28.9 | 380 | 72.20 | 5.4 |
| 210 | 39.90 | 27.6 | 385 | 73.15 | 5.2 |
| 215 | 40.85 | 26.3 | 390 | 74.10 | 5.0 |
| 220 | 41.80 | 25.1 | 395 | 75.05 | 4.7 |
| 225 | 42.75 | 23.9 | 400 | 76.00 | 4.5 |

*Figure B.1 The table shows the relation between barrier thickness and pressure for HWC donor.*