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Characterization of MCX-8100

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English summary

Independent of application, certain explosive composition properties are important to know. Performance depends on properties like detonation velocity and detonation pressure. Sensitivity of munitions is dependent on properties such as critical diameter to fulfill IM requirements. MCX-8100, studied in this report, is one of the new compositions developed with large critical diameter to withstand shock threat in the form of Bullet Attack, Fragment Impact, Sympathetic Detonation and Shaped Charge Jet Attack.

MCX-8100 is a composition developed and produced by Chemring Nobel. It is a melt-cast composition with main applications in large calibre fillings, for example 120 mm and 155 mm shells. We have characterized MCX-8100 due to potential for utilisation in these ammunition types. MCX-8100 has DNAN as binder. The solid filler is a mixture of NTO and HMX. Nominal content for MCX-8100 is NTO/DNAN/HMX (53/35/12). Selecting DNAN as binder makes it possible to use the same filling plants as for TNT or TNT based compositions to fill MCX-8100 into warheads.

MCX-8100 has been characterized with regards to critical diameter, detonation velocity and detonation pressure. In addition, theoretical calculations of performance at different densities have been performed with Cheetah 2.0.

The quality of the casted test items with regard to density is variable. Most items have a density of 97+2 % of TMD (Theoretical Maximum Density). X-ray images of the charges show lower density in the upper part than at the bottom. In addition, the casted items contain some bubbles, particularly in the upper part of the charges. The casting process has large potential for improvement.

Critical diameter for MCX-8100 Lot DDP13A0002E seems relatively reproducible. Four test items have been tested giving a critical diameter of 19.7 mm.

Detonation velocities have been determined for cylindrical charges with diameter 36+1 mm. Detonation velocity varies with the density of the charges. Average detonation velocity for the four tested items with average density 1.72+0.02 g/cm3 is 7106+148 m/s. This result is 3-400 m/s below the theoretical velocity calculated with Cheetah 2.0

Average detonation pressure determined by Plate Dent test for 2 test charges is 208 kbar. As for the detonation velocity this result is below the theoretical result calculated by Cheetah 2.0. The difference is in order of 20+10 kbar.

Sammendrag

Uavhengig av hva en sprengstoffkomposisjon skal brukes til, er det noen egenskaper som er viktig å ha kjennskap til. Virkningen til sprengstoff er avhengig av egenskaper som detonasjonshastighet og detonasjonstrykk, mens følsomhet til ammunisjon er avhengig av egenskaper som kritisk diameter for å kunne oppfylle kravet til IM. MCX-8100 er en av de nye komposisjonene utviklet med stor kritisk diameter for å motstå trusselen fra sjokk. For IM testene Bullet Attack, Fragment Impact, Sympathetic Detonation og Shape Charged Jet Attack er hovedtrusselen sjokk som gir sjokkinitiering av sprengstoffet.

Komposisjonen MCX-8100 er utviklet og produsert av Chemring Nobel. Det er en smeltestøpt komposisjon som kan anvendes i større kalibre som 120 mm og 155 mm granater. Vi har karakterisert komposisjonen utfra dens potensiale for bruk i denne type ammunisjon. MCX-8100 har DNAN som bindemiddel. Faststoffet er en blanding av NTO og RDX. Nominell sammensetning for MCX-8100 er NTO/DNAN/HMX (53/35/12). Ved å bruke DNAN som bindemiddel kan alle fyllingsanlegg for TNT eller TNT-baserte komposisjoner også benyttes til fylling av MCX-6100.

I denne rapporten har ulike prøver av MCX-8100 blitt karakterisert med hensyn på kritisk diameter, detonasjonshastighet og detonasjonstrykk. I tillegg er teoretiske beregninger av virkning ved ulike tettheter blitt utført ved bruk av Cheetah 2.0.

De støpte testlegemene varierer i kvalitet med hensyn på tetthet. De fleste testlegemer hadde en tetthet på 97+2 % av TMD. Røntgenbilder av ladningene viser lavere tetthet i toppen enn i bunnen. I tillegg inneholder de støpte ladningene luftbobler/porer som også i stor grad er konsentrert til den øvre halvdel av ladningene. Benyttet støpeprosedyre har derfor utvilsomt potensiale for forbedringer.

Kritisk diameter for MCX-8100 Lot DDP13A0002E er reproduserbar. Fire testobjekter er testet og har alle en kritisk diameter på 19,7 mm.

Detonasjonshastighet er bestemt for ladninger med diameter 36+1 mm. Detonasjonshastigheten varierer med tettheten på testladningen. Gjennomsnittshastigheten for de fire testlegemene med gjennomsnittlig tetthet 1,72+0,02 g/cm3 er målt til 7106+148 m/s. Dette resultatet er 3-400 m/s lavere enn den teoretisk beregnede detonasjonshastigheten med Cheetah 2.0.

Detonasjonstrykk bestemt ved bruk av Plate Dent-test for to testladninger gir et gjennomsnittlig trykk på 208 kbar. Eksperimentelt målt detonasjonstrykk er lavere enn teoretisk beregnet med Cheetah 2.0. Forskjellen er i størrelsesorden 20+10 kbar.

Contents

Abbreviations

BAMO	3,3-Bis-azidomethyl oxetane
DNAN	2,4-dinitroanisole
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)
MCX	Melt Cast Explosive
MCX-6002	NTO/TNT/RDX (51/34/15)
MCX-6100	NTO/DNAN/RDX (53/32/15)
MCX-8001	NTO/TNT/HMX (52/36/11)
MCX-8100	NTO/DNAN/HMX (53/35/12)
NTO	3-Nitro-1,2,4 Triazol 5-one
PAX-48	NTO/DNAN/HMX (53/35/12)
RDX	Hexogen/1,3,5 -trinitro-1,3,5-triazacyclohexane
TMD	Theoretical Maximum Density
TNT	2,4,6-trinitrotoluene

1 Introduction

In EDA project arrangement No B-0585-GEM2-GC “Formulation and Production of New Energetic Materials” different melt-cast compositions and compositions containing GA/BAMO polymers have been studied. Norway’s main activity in the project was on synthesizing GA/BAMO polymers suitable for nitramine coating. The objective was to obtain coated nitramines or press granules with properties suitable for press filling of munitions units or for 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 in propellant formulations. The compositions Norway produced had high content of HMX and their primary applications will be as boosters or main filling for shaped charges.

To broaden the number of different compositions included in WP 4000 - generic fragmentation testing of 40 mm shell, Norway included 4 melt-cast compositions. These compositions are all of interest for Norway as main filler preferentially for large caliber munitions. By using compounds like NTO and DNAN/TNT in the main explosive fillings munitions with these compositions will have the possibility to fulfil the IM requirements given in STANAG 4439 (1). Of the 4 compositions two of them have TNT and the other two have DNAN as binder. The filler is NTO/RDX or NTO/HMX. These compositions have in addition to the fragmentation performance been characterized for the most important properties detonation velocity, detonation pressure and critical diameter. In addition the shock sensitivity for the two compositions containing RDX has been determined (2, 3).

Dinitroanisole (DNAN) is a key IM melt-phase ingredient that is currently applied in several IM melt-pour formulations developed by the U.S. Army and the Australian DSTO (4-8). Current interest in DNAN has arisen primarily due 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 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 MCX-8100 has been characterized with regard to critical diameter, detonation velocity and detonation pressure. MCX-8100 contains DNAN as binder and the filler is NTO/HMX. Nominal content of MCX-8100 is NTO/DNAN/HMX (53/35/12). This composition has NTO/HMX content in the same range as the DNAN based US composition PAX-48 (53/35/12) (9) and the TNT based Chemring MCX-8001 composition (NTO/TNT/HMX (52/36/11). Critical diameter has been determined by the use of cylindrical charges of different diameter and witness plates (10, 11). Detonation velocity was measured for cylindrical charges by the use of 4-6 ionization pins (12, 13). Detonation pressure was determined by use of the Plate Dent test (14, 15).

2 Experiments

2.1 Detonation velocity and pressure

2.1.1 Casting

The samples for detonation velocity and pressure determination were all casted in Bjørkborn by Nammo Liab with explosives produced by Chemring Nobel in Norway. The moulds were polypropylene measuring cylinders with slightly conical form. Figure 2.1 shows a picture of the cylinders filled with MCX-8100 compositions. The explosive Lot No was DDP13A0002E.

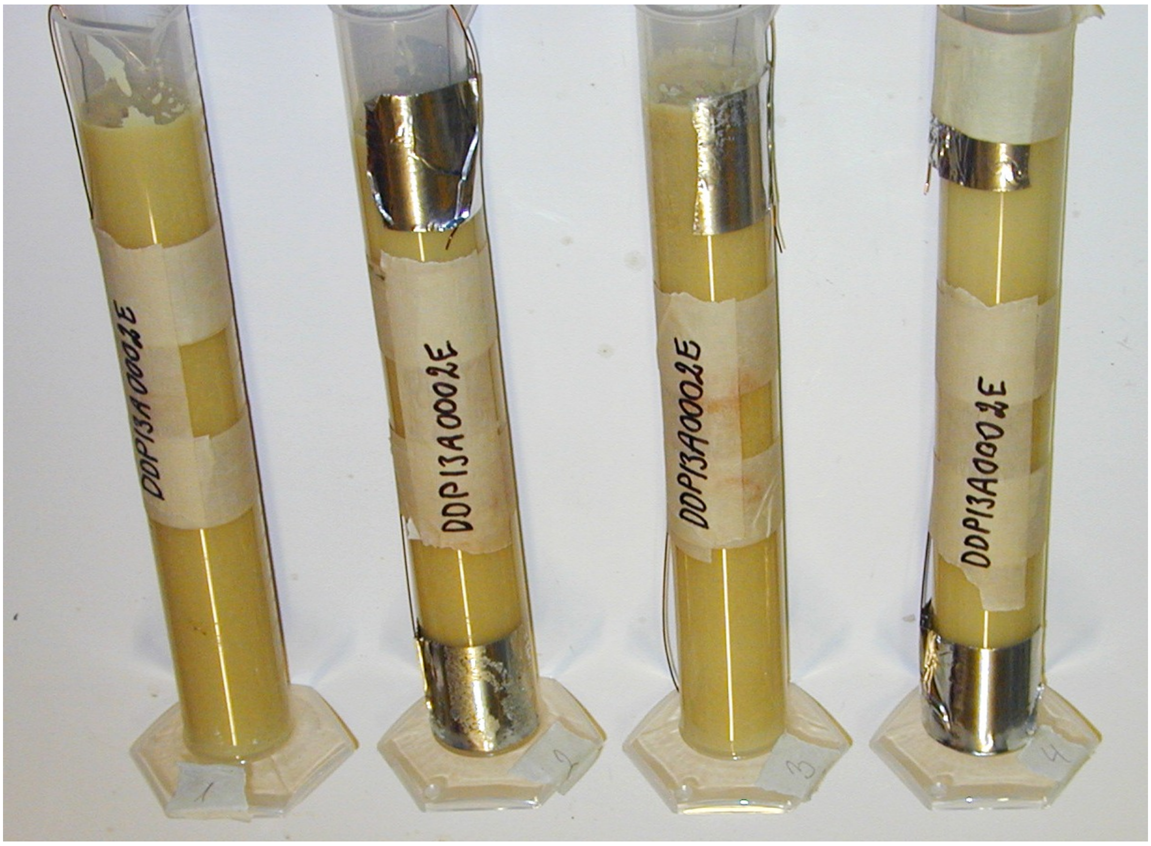

Figure 2.1 Picture of the tubes filled with MCX-8100 composition after casting.

2.1.2 X-ray

Visual inspection of the casted samples showed empty space on top. During solidification this composition has large volume changes. To clarify the quality it was decided to X-ray all tubes. X-raying was performed at Nammo Raufoss. Figure 2.2 shows a picture of the X-ray film of the tubes. The picture shows that the quality of the casted fillings varies a lot. Large voids on top, pores and area of low density are present for all fillings. All cylinders have areas in the bottom where the density seems acceptable. This area is largest for tube No 1.

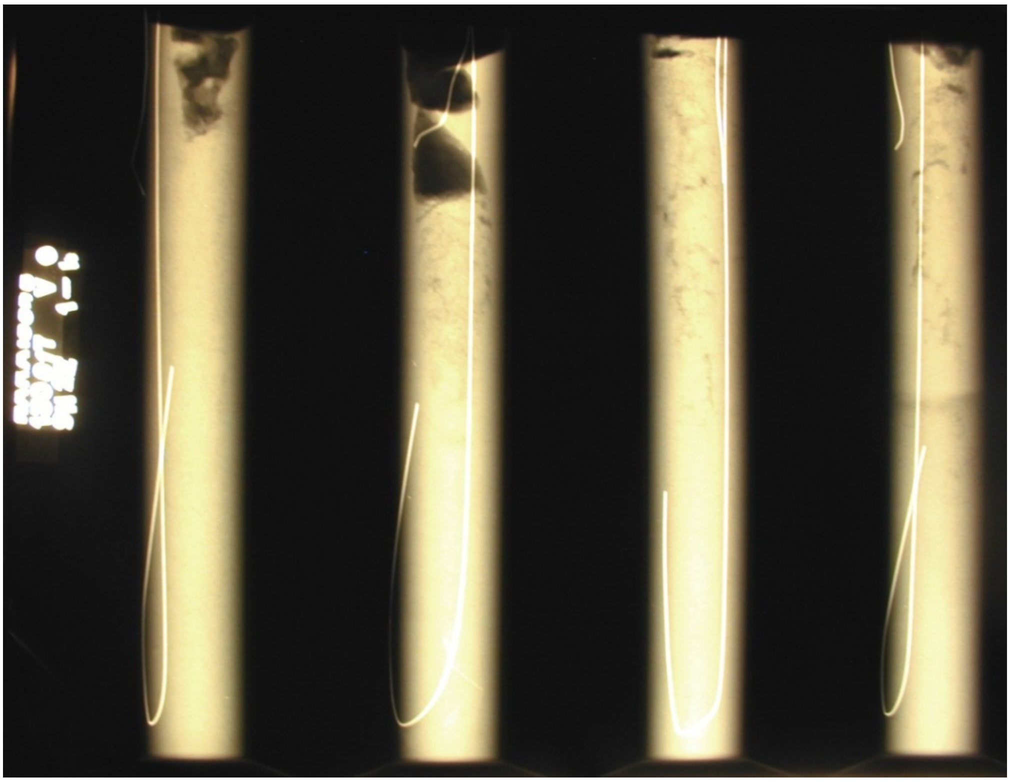

Figure 2.2 X-ray image of the MCX-8100 samples.

2.1.3 Density measurements

As shown by the X-ray picture in Figure 2.2 the quality of the casted cylinders was not good. However we decided to use those parts of the charges with lowest content of voids and defects to determine detonation velocity and pressure (Figure 2.3).

Figure 2.3 Picture of the parts of the charges that were found acceptable for detonation velocity determination.

First the plastic cylinder was removed by cutting off the foot and then split the cylinder in the longitudinal direction. The parts with satisfactory density were cut off the tubes by sawing. Table 2.1 summarizes the properties of these charges.

Tube No	Weight (g)	Height (mm)	Diameter bottom (mm)	Diameter Top (mm)	Average Radius (cm)	Volume (cm^3)	Density (g/cm^3)
1	158.41	85.36	36.85	37.47	1.852	92.2765	**1.711**
	226.75	128.10	35.80	36.75	1.81375	132.3895	**1.713**
2	214.75	119.04	35.75	36.75	1.8125	122.8567	**1.748**
3	293.76	162.95	35.78	37.08	1.80215	169.8488	**1.730**
4	220.69	124.80	35.74	36.80	1.8135	128.9455	**1.712**

Table 2.1 Summary of the dimensions and properties of the charges of MCX 8100 which were used for detonation velocity and pressure determination.

TMD for MCX-8100 is 1.765 g/cm^3. The density 1.711 g/cm^3 is equal to 96.94 %TMD and the highest density of 1.748 g/cm^3 is equal to 99.04 %TMD.

2.1.3.1 Detonation velocity measurements

The ionization pins and setup for registration on the scope is described in (12).
The scope we used to collect the results was a GW Instek GDS-3352, Digital Storage Oscilloscope, 350 MHz 5 GS/s adjusted to DC. A summary of conditions under the test firings is given in Table 2.2.

Figure 2.4 The test item used for determination of detonation velocity.

	Firing No 1	Firing No 2
Memory Length	25000	25000
Trigger Level	-2.64V	-2.64V
Source	CH1	CH1
Probe	1.000E+00	1.000E+00
Vertical Units	V	V
Vertical Scale	2.000E+00	2.000E+00
Vertical Position	4.000E+00	4.000E+00
Horizontal Units	S	S
Horizontal Scale	1.000E-05	1.000E-05
Horizontal Position	3.990E-05	3.990E-05
Horizontal Mode	Main	Main
Sampling Period	4.000E-09	4.000E-09
Firmware	V1.09	V1.09
Time	14.03.2014 10:45	14.03.2014 13:11
Mode	Detail	Detail
Waveform Data		

Table 2.2 Scope specifications and settings used.

2.1.4 Pressure determination

Pressure determination was performed by use of the Plate Dent test (14, 15). As witness plate we used cylindrical plates with diameter 160 mm and 60 mm thickness. Certificate is given in Appendix A. To measure the Dent we used a ring, bullet and micro meter screw as shown in Figure 2.5.

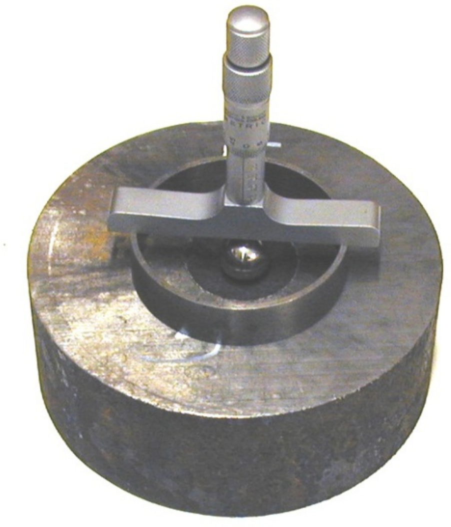

Figure 2.5 Picture of the tool used to measure the Dent depth.

2.2 Critical Diameter

2.2.1 Charges

Cylindrical charges with 5 different diameters were casted by Nammo Liab for determination of critical diameter (10, 12). The casting was performed in measuring cylinders from which charges with length 2 times the diameter were cut by sawing. Figure 2.6 shows pictures of all charges as received in plastic moulds and as the charges were organized during X-ray analysis.

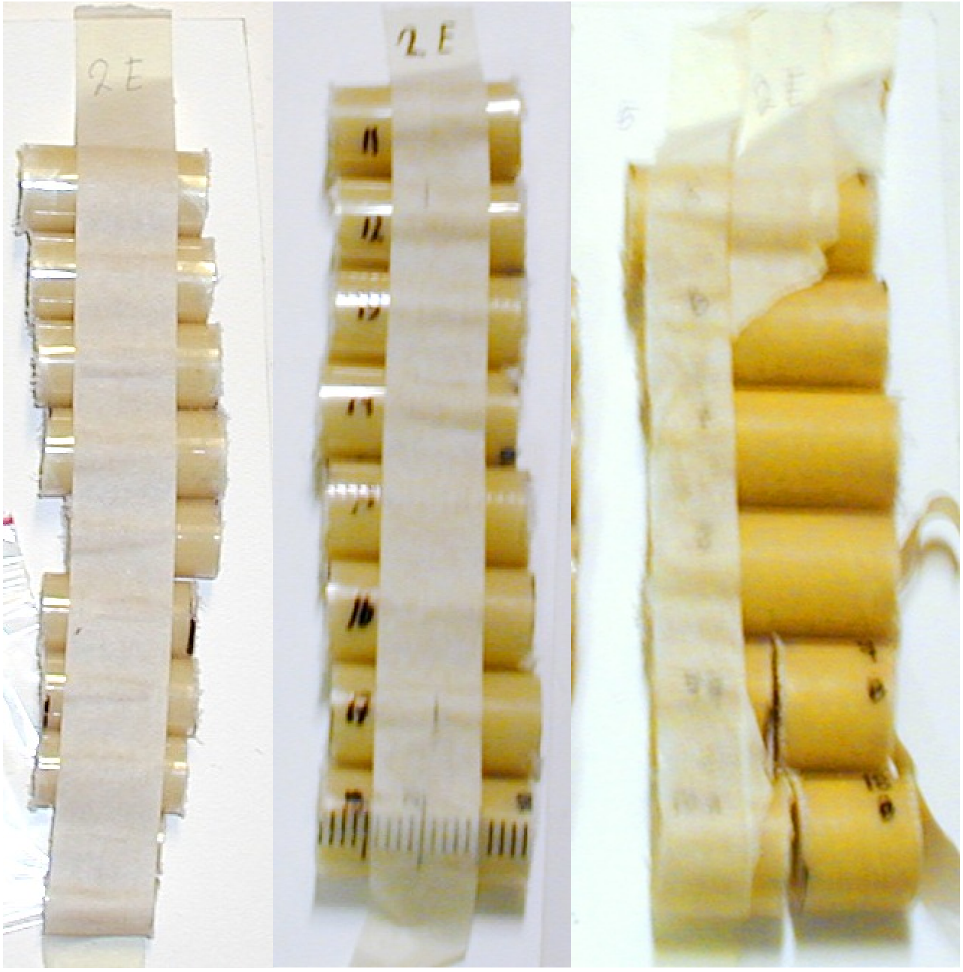

Figure 2.6 Pictures of the charges of MCX-8100 received for determination of critical diameter.

2.2.2 X-ray of the charges

All tubes were X-rayed with a 320 kV apparatus at Nammo Raufoss. Figure 2.7 shows pictures of X-ray films of the charges in Figure 2.6. As the pictures show there are dark areas in many of the charges indicating reduced density. Thus the quality with regard to density could have been better.

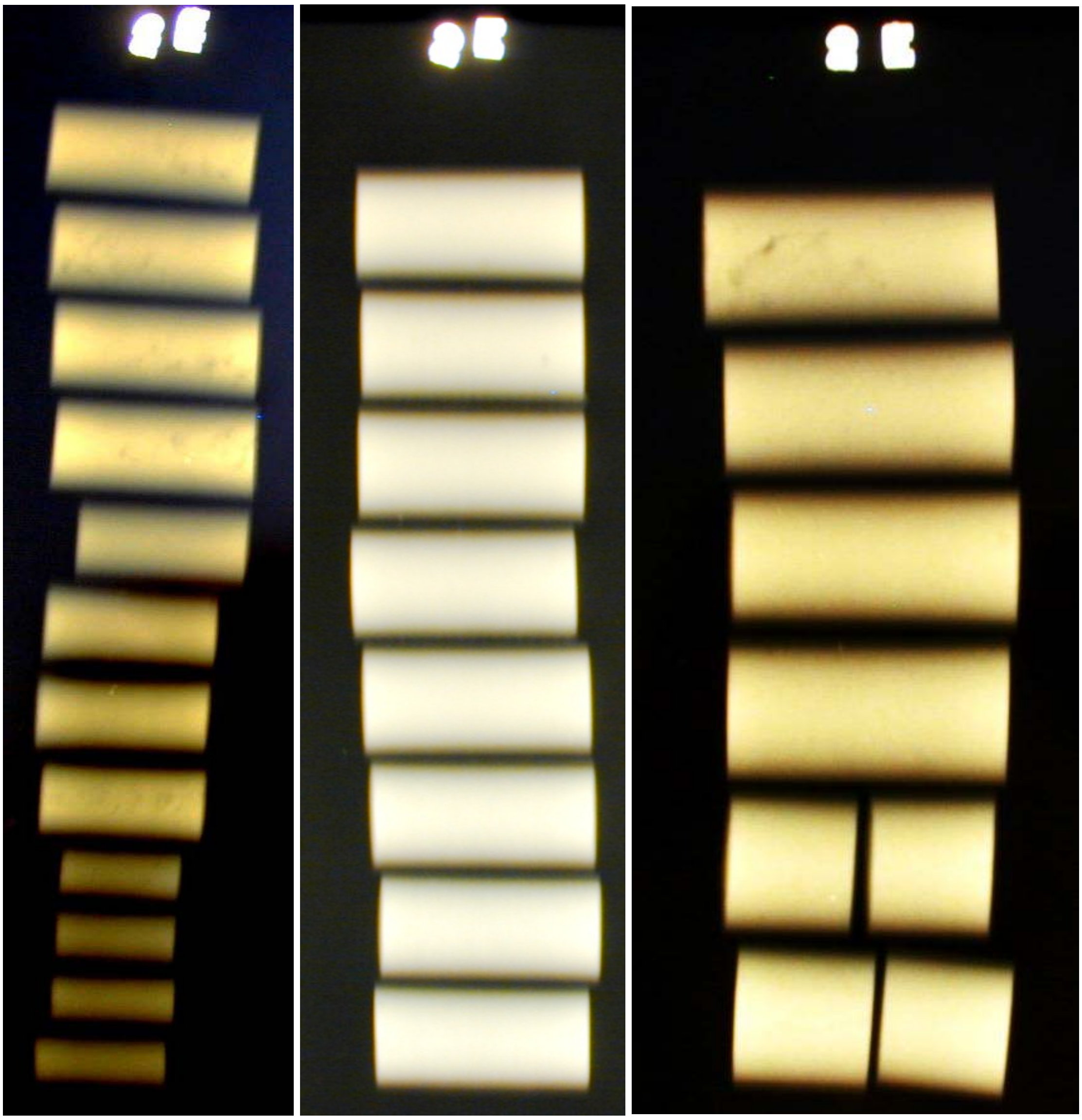

Figure 2.7   X-ray pictures of the test items given in Figure 2.6.

2.2.3 Density

After the charges were X-rayed they were released from the moulds and dimensions and weight of each pellet were measured. Table 2.3 gives all measured and calculated properties. The measured density of 1.72 g/cm^3 is moderate and as the X-ray pictures show there are areas with low density in most pellets. TMD for MCX-8100 is 1.765 g/cm^3. The majority of the pellets have a density of 97.5$\pm$0.5 % of TMD.

Pellet No	Weight (g)	Height (mm)	Upper diameter (mm)	Lower Diameter (mm)	Average Radius (mm)	Volume (mm^3)	Density (g/cm^3)
	DDP13A0002E No 1						
1	4.3503	25.85	10.77	11.15	5.48	2438.8	1.78
2	4.3556	25.78	10.78	11.17	5.49	2438.8	1.79
	DDP13A0002E No 2						
1	11.2675	35.63	14.85	15.33	7.55	6372.1	1.77
2	11.4011	37.05	14.83	15.27	7.53	6591.0	1.73
3	11.2779	36.90	14.80	15.28	7.52	6555.6	1.72
4	11.2798	35.44	15.23	15.67	7.73	6644.2	1.70
	DDP13A0002E No 3						
1	23.6735	45.11	19.64	19.79	9.86	13770.7	1.72
2	23.2947	44.56	19.59	19.76	9.84	13547.7	1.72
3	23.4805	44.66	19.60	19.84	9.86	13640.3	1.72
4	22.6192	43.45	19.60	19.78	9.85	13230.3	1.71
	DDP13A0002E No 4						
5	49.8416	56.72	25.22	25.91	12.78	29115.1	1.71
6	48.9095	55.26	25.24	25.90	12.79	28376.7	1.72
7	48.7383	54.83	25.26	25.84	12.78	28111.9	1.73
8	47.4472	53.39	25.27	25.90	12.79	27448.6	1.73
	DDP13A0002E No 5						
11	31.7281	49.35	21.54	22.03	10.89	18394.7	1.72
12	31.8980	48.30	21.92	22.37	11.07	18603.2	1.71
13	31.7879	49.23	21.56	22.13	10.92	18451.2	1.72
14	32.6959	49.22	21.95	22.38	11.08	18991.8	1.72
15	32.4683	50.17	21.53	22.15	10.92	18794.9	1.73
16	31.9050	49.70	21.52	22.13	10.91	18593.2	1.72
17	32.7375	49.40	21.93	22.37	11.08	19035.5	1.72
18	32.2291	48.50	21.95	22.38	11.08	18714.0	1.72

Table 2.3 Properties of pellets used for determination of critical density.

2.2.4 Test items preparation

After the pellets had been measured they were glued together by use of “Casco Kontaktlim”. Figure 2.8 shows the test items with booster after assembled by gluing. The two test items at left contain 5 charges with diameters from 11 mm to 26 mm. The two test items to the right contain each 4 charges with diameters from 26 mm to 15 mm.

Figure 2.8 Pictures of the test items for determination of critical diameter.

2.3 Initiation

All charges have been initiated by a detonator No 8 and with a 35 g booster of HWC (95/RDX/ 5 WAX). The booster had a diameter of 31.8 mm and was pressed with a pressure of 10 tons and dwell time of 60 s. The certificate of the booster explosive is given in Appendix B.

2.4 Theoretical calculations

Theoretical calculation has been performed by use of Cheetah 2.0 (16). Summary printouts are given in Appendix C.

3 Results

3.1 Critical diameter

3.1.1 Firing No 1

The critical diameter for MCX-8100 was determined by firing of charges of different diameters glued together to a test item having diameters from 26 mm to 11 mm (10, 11). Each charge had a length which was twice the diameter. Applied test method is described in reference (11). Figure 3.1 shows pictures of the test setup and the witness plate after firing. The two charges with diameter 25.6 and 22 mm both have full detonation in the whole length. For charge No 3 having diameter 19.79 mm at top and 19.64 mm at bottom the detonation stops approximately when 1/3 of the charge has reacted. Most of the two charges with smallest diameter were unreacted and recovered after the firing.

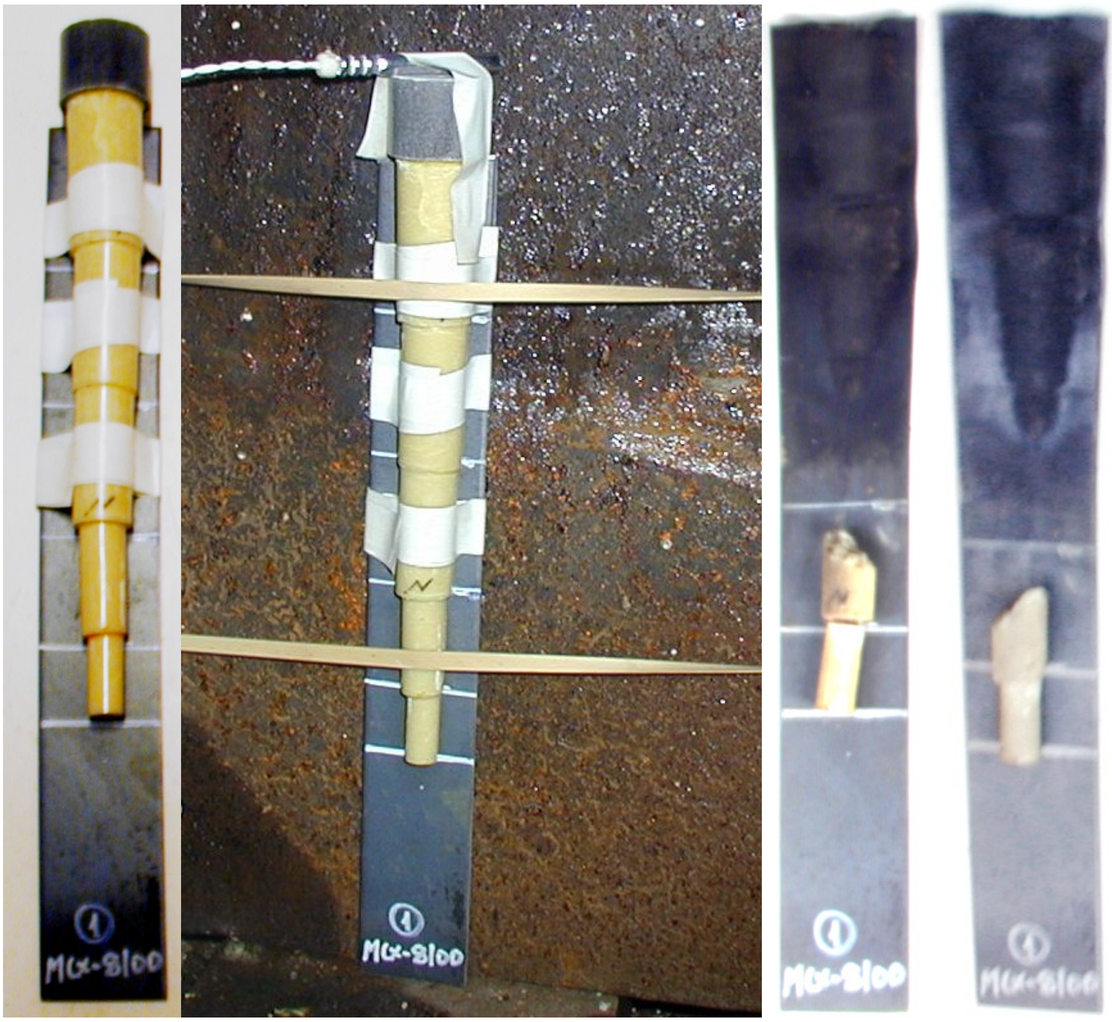

Figure 3.1 Pictures of the test setup and witness plate including recovered explosive for firing No 1.

From the witness plate of this firing the critical diameter is found to be 19.7 mm.

3.1.2 Firing No 2

The second firing was performed with a test item containing 5 charges of different diameters. Figure 3.2 shows pictures of the test setup and the witness plate after firing. The charges with diameter 25.6 and 22.1 mm detonated in the whole length. For charge No 3 having diameter 19.76 mm at top and 19.59 mm at bottom the detonation stops approximately when 1/2 of the charge length has reacted. For the two charges with smallest diameter no reaction took place, and some unreacted material from both charges was recovered after the firing.

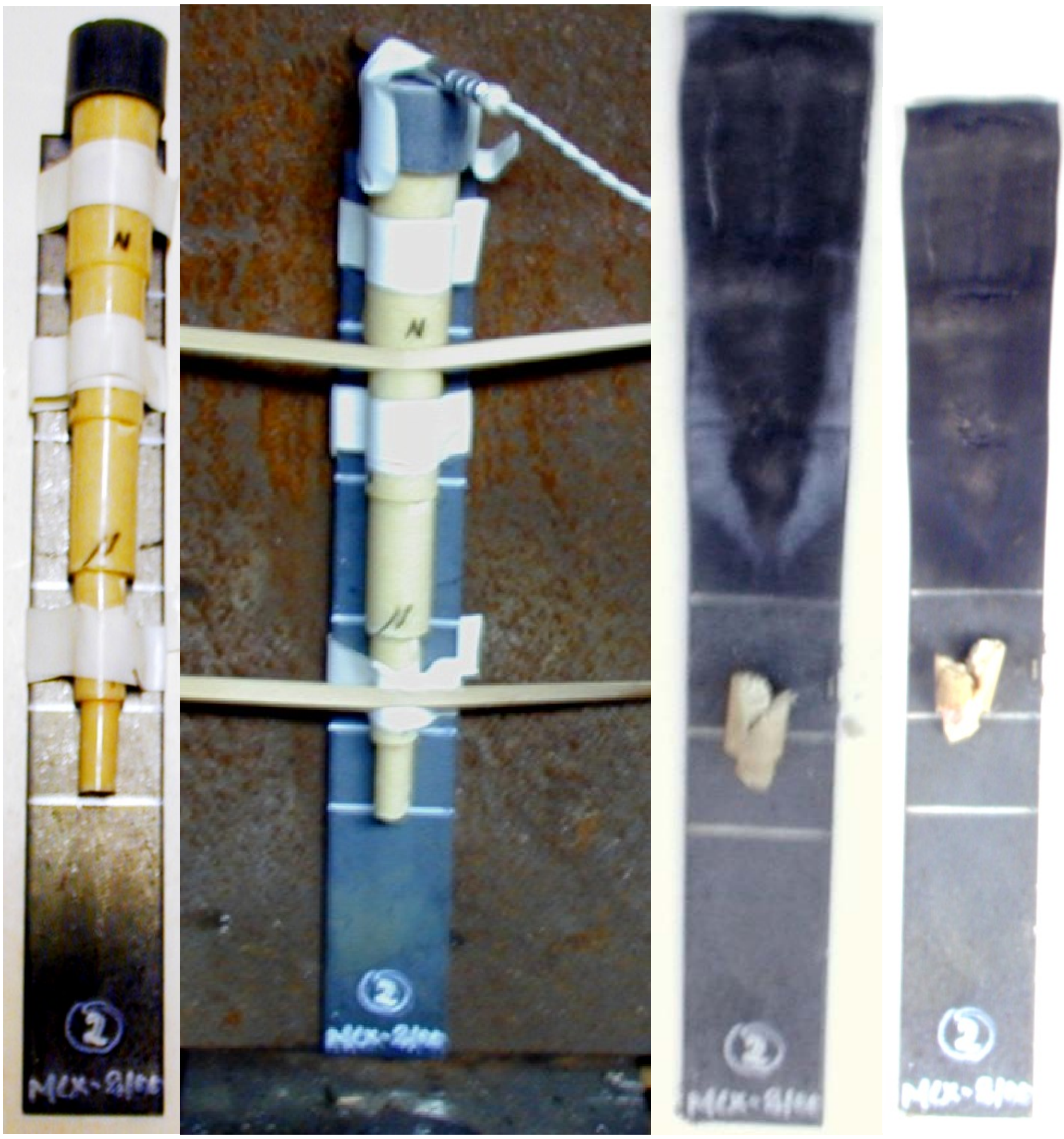

Figure 3.2 Pictures of the test setup and witness plate including recovered explosive for firing No 2.

From the witness plate of this firing the critical diameter is found to be 19.7 mm.

3.1.3 Firing No 3

The third firing was performed with a test item containing 4 charges of different diameters. Figure 3.3 shows pictures of the test setup and the witness plate after firing. The charges with diameters 25.6 and 21.8 mm detonated in the whole length. For charge No 3 having diameter 19.84 mm at top and 19.60 mm at bottom the detonation stops approximately when 1/2 of the charge length has reacted. For the charge with smallest diameter no reaction took place, and unreacted material was recovered after the firing.

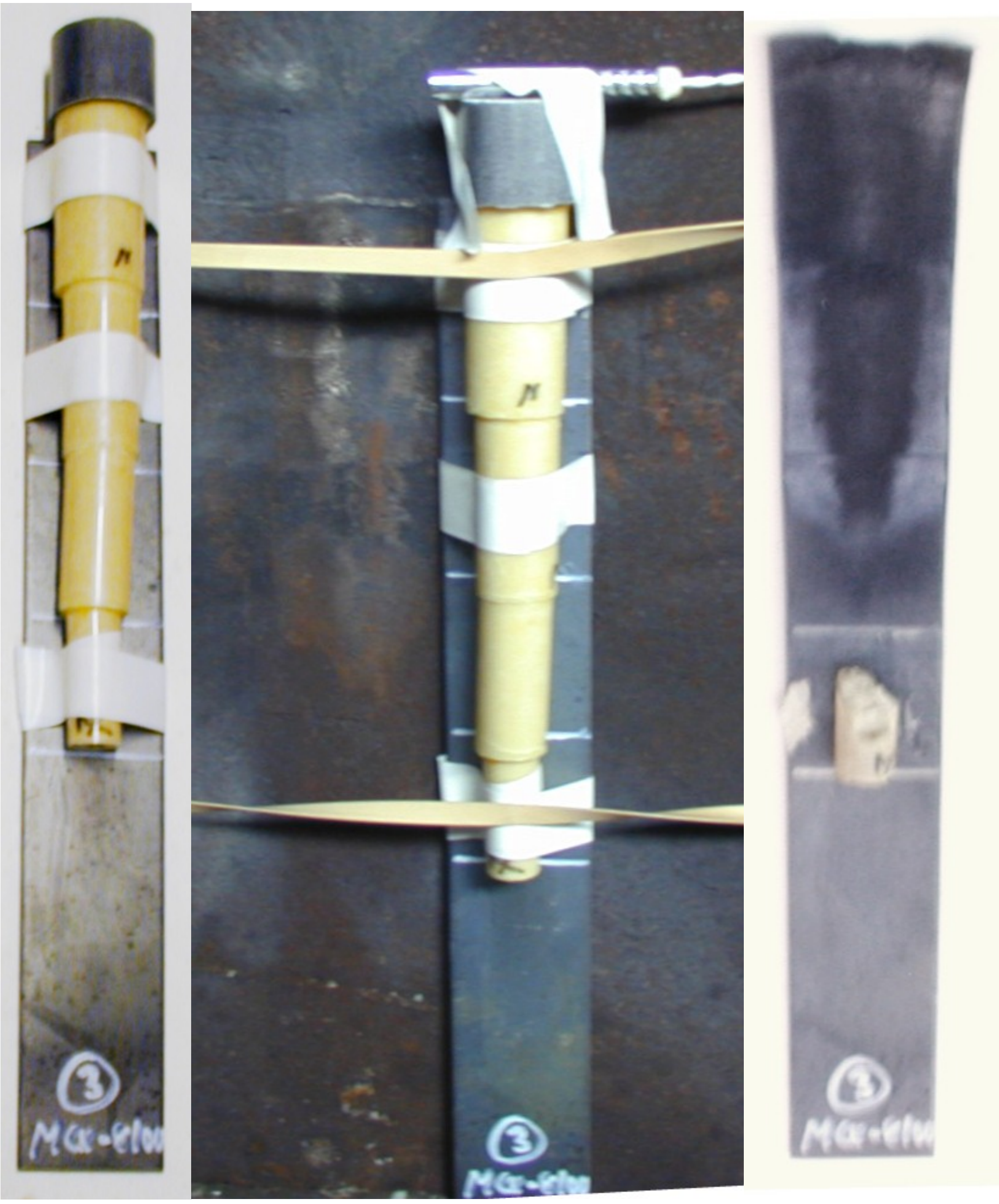

Figure 3.3 The above pictures show test setup and witness plate after firing for firing No 3.

From the witness plate of this firing the critical diameter is found to be 19.7 mm.

3.1.4 Firing No 4

The fourth test was performed with a test item containing 4 charges of different diameters. Figure 3.4 shows pictures of the test setup and the witness plate after firing. The charges with diameters 25.6 and 22.2 mm detonated in the full length. For charge No 3 having diameter 19.78 mm at top and 19.60 mm at bottom the detonation stops approximately after 4/5 of the charge length has reacted. For the charge with the smallest diameter no reaction took place, and no unreacted material was recovered after the firing.

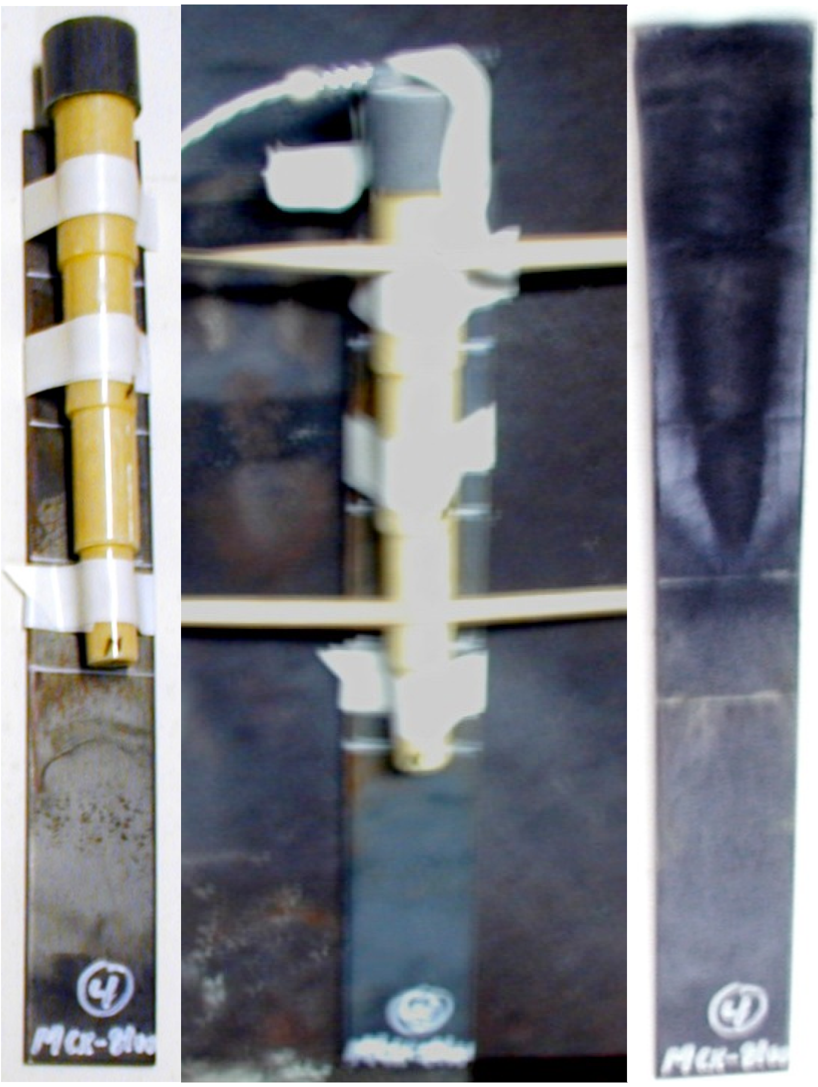

Figure 3.4 Pictures of the test setup and witness plate for firing No 4.

From the witness plate of this firing the critical diameter is found to be 19.7 mm.

3.1.5 Summary of the results

Figure 3.5 gives a picture of all four witness plates with recovered unreacted material from three of the firings. For all tests the reaction stops in the charge No 3 with diameter between 19.8 mm and 19.6 mm giving a critical diameter of 19.7 mm. The variation in the results is minimal for this lot of MCX-8100.

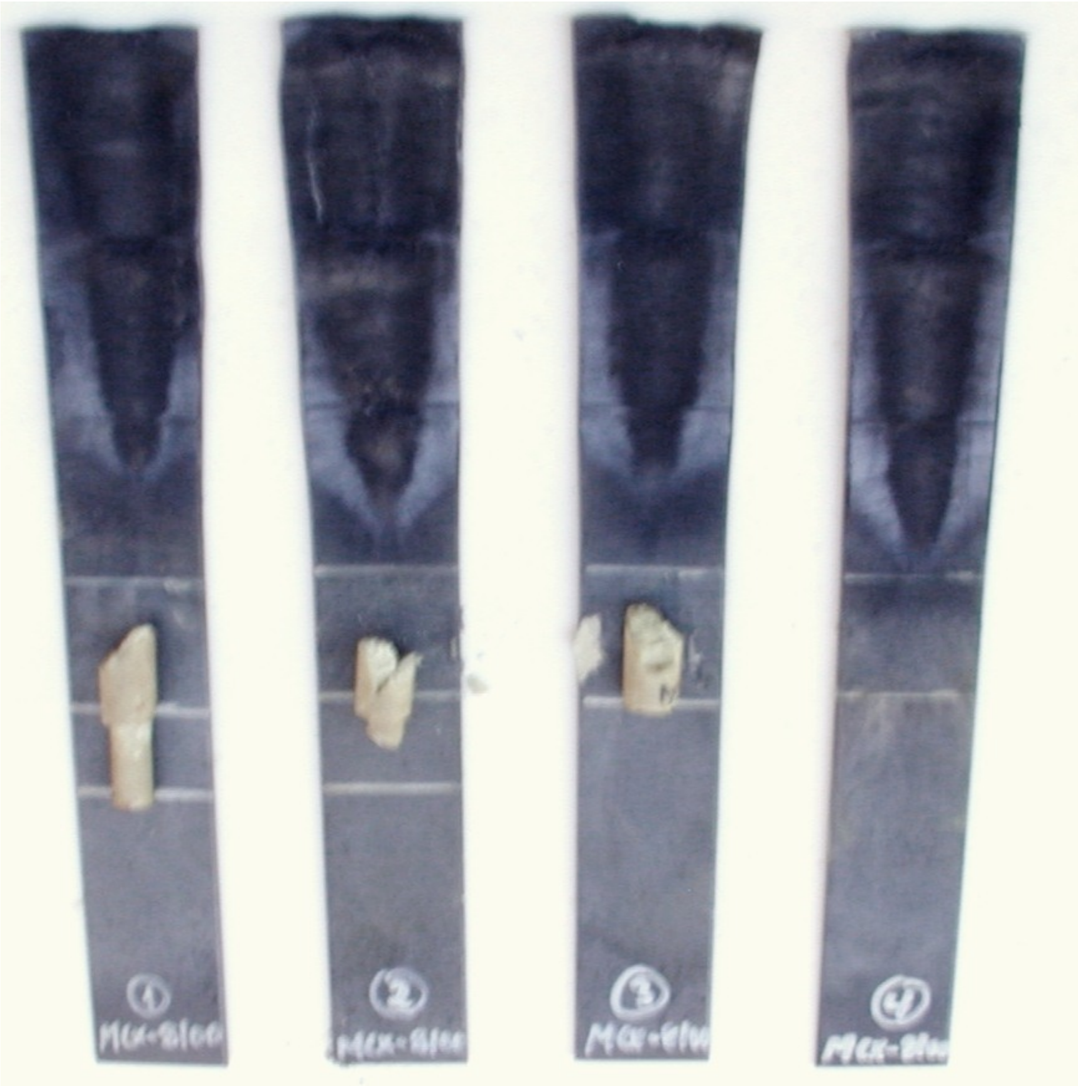

Figure 3.5 Pictures of the witness plates including recovered explosives for firings with MCX-8100 test items for determination of critical diameter.

The obtained critical diameter is in the range of what is reported in literature of 0.75 -1 inch (or 18-25 mm) (9).

3.2 Detonation velocity

3.2.1 Firing No 1

The lower part of the test item was made up from charge No 3 and the upper part was from charge No 4. The test item contains 4 ionization pins, two in the upper and two in the lower part of the charge. The distances between the ionization pin No 1 and pin No 2 and between pin No 2 and pin No 3 were both 50 mm. Between ionization pin No 3 and pin No 4 the distance was 100 mm. Figure 3.6 shows pictures of the test item after it was assembled and of the test setup before firing. Figure 3.7 shows the arrival times of the detonation front for all ionization pins. Registrations were obtained for all ionization pins.

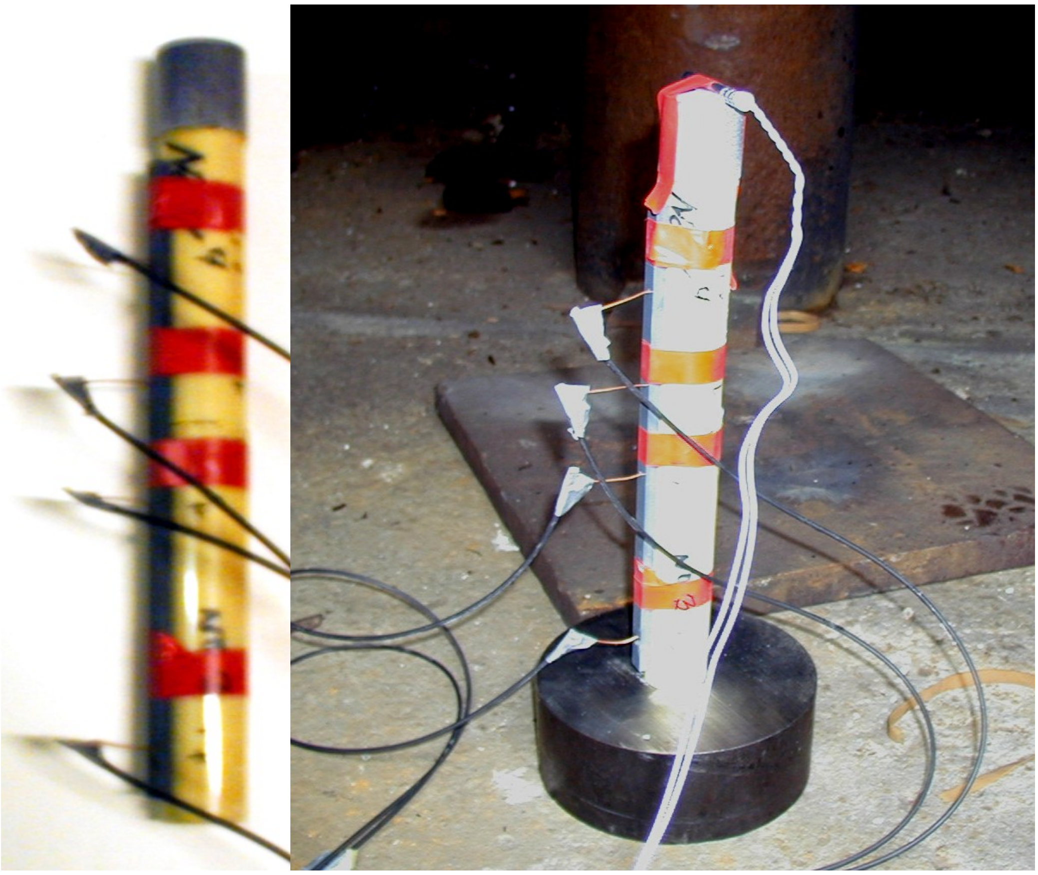

Figure 3.6 The assembled test item and the setup for firing No1 with MCX-8100.

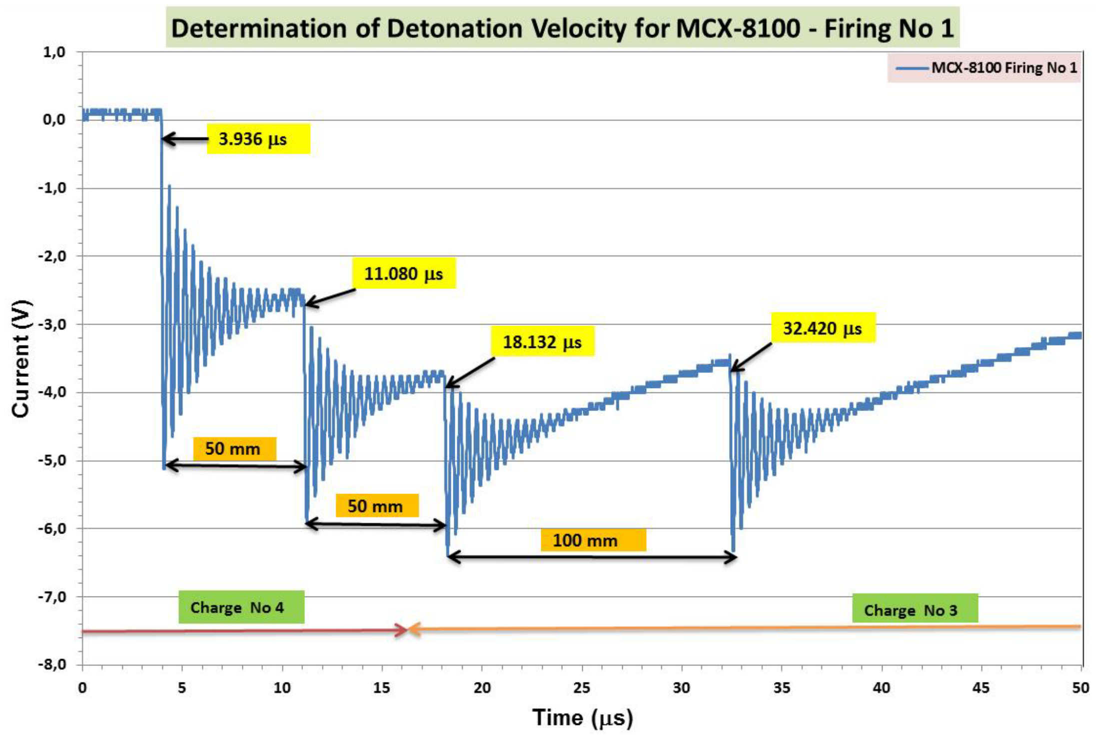

Figure 3.7 The arrival times of the detonation front for all ionization pins in addition to the distance between the pins.

Obtained detonation velocities between the different ionization pins are summarized in Table 3.1. The detonation velocity is the same for both charge No 3 and No 4 (6999 m/s). The velocity over the distance containing the transition between the two charges is slightly higher (7090 m/s).

Pin No	Arrival time (µs)	Time between Pin No X and X-1 (µs)	Distance from Pin X to Pin X-1 (mm)	Detonation Velocity (m/s)
	Firing No 1 containing MCX-8100			
1	3.936			
2	11.080	7.144	50	**6999**
3	18.132	7.052	50	7090
4	32.420	14.288	100	**6999**
1-4		28.484	200	**7021**

Table 3.1 A summary of the measured detonation velocities for MCX 8100 test No 1.

3.2.2 Firing No 2

The test item was made up of the lower part from charge No 2 and the upper part was from the two parts of charge No 1. The test item contains 6 ionization pins, three in the upper main part of charge No 1 and three in the lower part of the charge from cast (tube) No 2. The distance between the ionization pins was 30 mm between pin No 1 and pin No 2, 60 mm between pin No 2 and pin No 3, 30 mm between pin No 3 and pin No 4 and pin No 4 and pin No 5. Between pin No 5 and pin No 6 the distance was 60 mm. Figure 3.8 shows a picture of the test item after it was assembled. The first firing failed, only the detonator and the booster reacted. There was no detonation transfer from the booster to the main charge. As the picture in Figure 3.8 shows, only the end of the charge in contact with the booster was disturbed. In the upper charge there was no ionization pins, so the complete charge was removed and a new booster and detonator was added. Figure 3.8 also shows the test setup after this modification of the test item. In the next trial the test item did detonate. However we did not get registration for ionization pin No 6. Figure 3.8 shows the scope with the actual registration for this firing.

Figure 3.9 shows the arrival times of the detonation front for the first 5 ionization pins in addition to the distances between all pins.

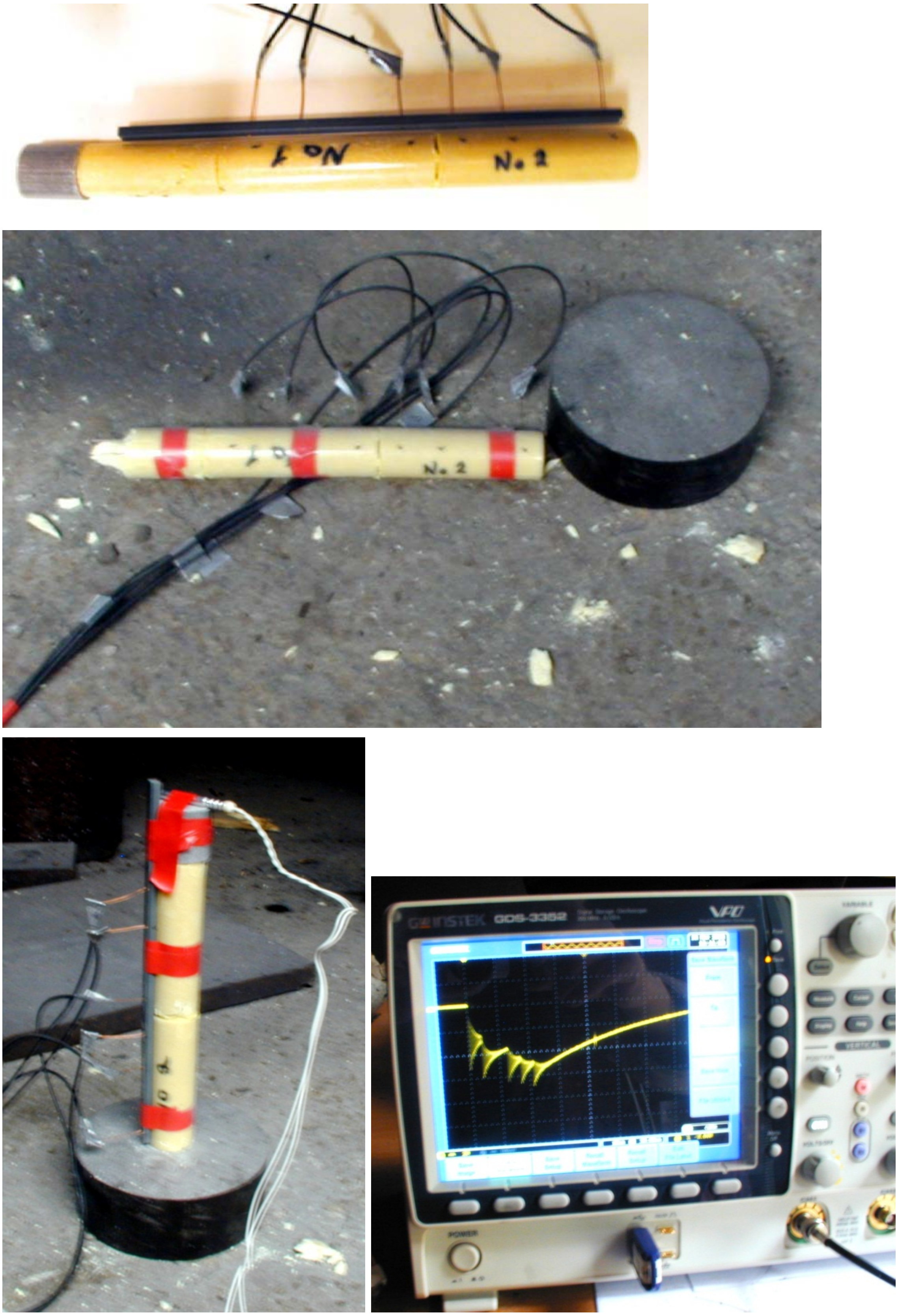

Figure 3.8 The figure shows the assembled test item, the test item after failed firing, modified test item and finally the scope used with the obtained registration after the firing.

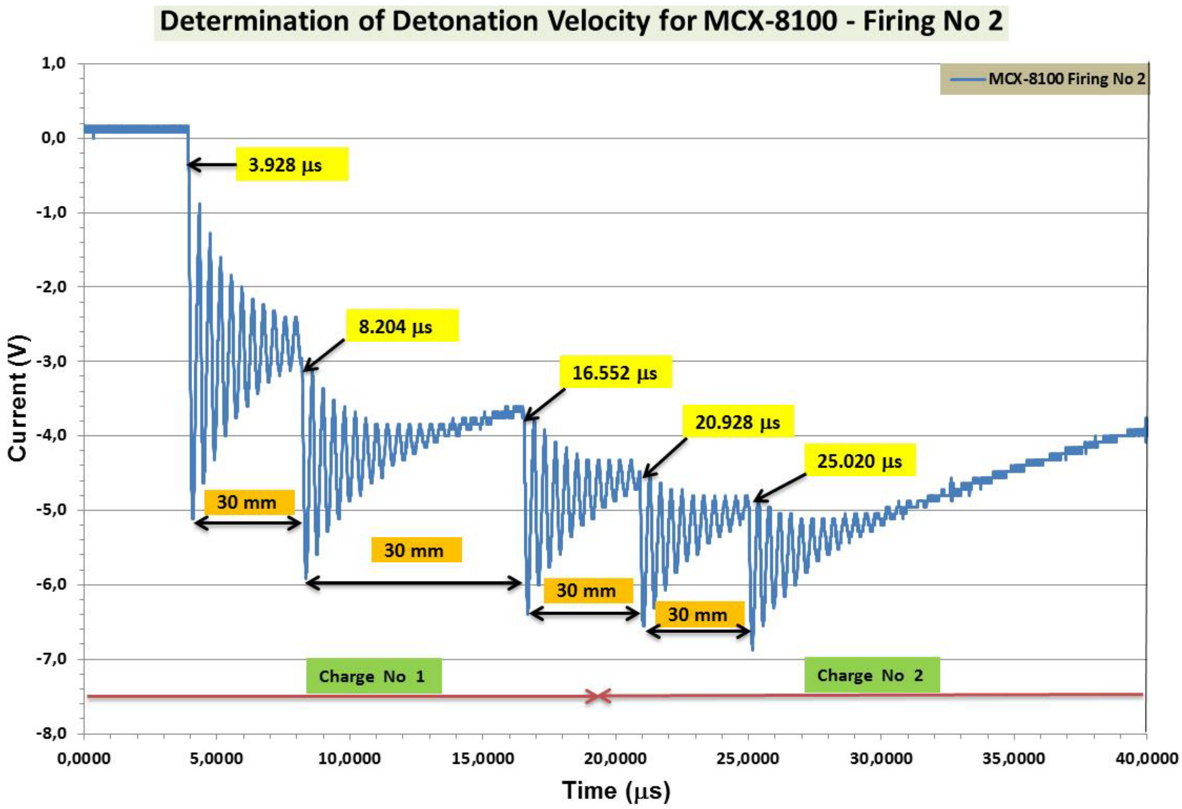

Figure 3.9 Arrival time of the detonation front for each ionization pin in addition to the distances between the pins.

Pin No	Arrival time (µs)	Time between Pin No X and X-1 (µs)	Distance from Pin X to Pin X-1 (mm)	Detonation Velocity (m/s)
	Firing No 2 containing MCX-8100			
1	3.928			
2	8.204	4.276	30	**7016**
3	16.552	8.348	60	**7187**
4	20.928	4.376	30	6856
5	25.020	4.092	30	**7331**
6	No registration		60	
1-5		21.092	150	7112

Table 3.2 A summary of the results from the determination of the detonation velocity for MCX 8100 test No 2.

Obtained detonation velocities between the different ionization pins are summarized in Table 3.2. For charge No 1 we have two results, between pin No 1 and pin No 2 a velocity of 7016 m/s and in the bottom of the charge between pin No 2 and pin No 3 a detonation velocity of 7187 m/s. This difference in velocities can be explained by expected higher density in the bottom of the charge. The velocity between pin No 3 and pin No 4 of 6856 m/s is for the transition between charge No 3 and No

4. The last velocity we obtained is between pin No 4 and pin No 5 of 7331 m/s. This is the highest velocities we have measured for MCX-8100 composition. Charge No 3 had the highest average density with 99 %TMD.

3.2.3 Summary of detonation velocity

In Table 3.3 individual detonation velocity measurements for the four tubes are given: The results are relatively reproducible but with some deviation due to different density of the tested items.

Charge No	Test No	Between Pin No	Measuring distance (mm)	Charge density (g/cm^3)	Detonation velocity (m/s)
1	2	1-2	30	1.713	**7016**
	2	2-3	60		**7187**
2	2	4-5	30	1.748	**7331**
3	1	3-4	100	1.730	**6999**
4	1	1-2	50	1.712	**6999**

Table 3.3 Detonation velocities obtained for the four tubes containing MCX-8100 DDP13A0002E composition.

3.3 Detonation pressure

The detonation pressure was measured for the two test items used for detonation velocity determination by use of the Plate Dent test. The plates used were cylindrical with diameter 160 mm and thickness 60 mm. Figure 3.10 shows pictures of the Dent plates after firing. Table 3.4 gives a summary of the obtained results. An average detonation pressure of 208 kbar was found for the tested MCX-8100 composition.

Figure 3.10 The Figure shows the Plate Dent witness plates for the two tested charges containing the MCX 8100 composition.

Shot No	From tube No	Charge diameter (mm)	Density (g/cm^3)	Dent Depth (mm)	Detonation pressure (kbars)
1	3+4	35.78	1.7295	5.30	**213.3**
2	1+2	35.75	1.7480	5.04	**203.0**
Average					**208.2**

Table 3.4 Results from determination of detonation pressure by the Plate Dent test for MCX-8100.

This result is better than for MCX-6100 with 190±7 kbar. However, the MCX-6100 had on average lower densities. For both DNAN compositions the experimentally determined detonation pressures are lower than expected.

3.4 Theoretical calculations

Theoretical calculations have been carried out by use of Cheetah 2.0 (16) for the nominal content of MCX-8100 at TMD. Appendix C gives the summary printout for these calculations with the two product libraries BKWC and BKWS.

Property		**Product Library**	
		BKWC	**BKWS**
TMD (g/cc)		**1.7650**	**1.7650**
The C-J condition:			
Pressure	**(GPa)**	**24.19**	**24.43**
Volume	**(cc/g)**	**0.433**	**0.437**
Density	**(g/cc)**	**2.312**	**2.290**
Energy	**(kJ/cc explosive)**	**2.86**	**2.80**
Temperature	**(K)**	**3367**	**3385**
Shock velocity	**(m/s)**	**7612**	**7770**
Particle velocity	**(m/s)**	**1801**	**1781**
Speed of sound	**(m/s)**	**5811**	**5988**
Gamma		**3.227**	**3.362**
Freezing occurred at T = 1800 K and relative V =		**1.728**	**1.740**
Mechanical energy of detonation	**(kJ/cc)**	**-7.543**	**-7.757**
Thermal energy of detonation	**(kJ/cc)**	**-0.000**	**-0.000**
Total energy of detonation	**(kJ/cc)**	**-7.543**	**-7.757**

MCX 8100: NTO/DNAN/HMX (53/35/12).

Table 3.5 Cheetah 2.0 calculations with BKWC and BKWS product libraries for MCX-8100 composition.

The experimentally determined detonation velocity and pressure are both lower than the calculated theoretical values even when the charge density is taken into consideration. Table 3.6 summarizes how detonation velocity and pressure depend on charge density for both product libraries used in these calculations. Appendix C gives summary printout for all calculations.

Density (g/cm^3)	% TMD	Product Library BKWC		Product Library BKWS	
		Detonation		Detonation	
		Pressure (GPa)	Velocity (m/s)	Pressure (GPa)	Velocity (m/s)
1.7650	**100.0**	24.19	7610	24.43	7770
1.7500	99.15	23.65	7560	23.91	7712
1.7400	98.58	23.29	7525	23.57	7674
1.7300	98.02	22.94	7490	23.23	7635
1.7200	97.45	22.59	7455	22.90	7597
1.7100	96.88	22.25	7420	22.57	7559

Table 3.6 Detonation pressure and velocity for different densities of MCX-8100 calculated with Cheetah 2.0.

4 Summary

MCX-8100 has been characterized with regard to critical diameter, detonation velocity and detonation pressure. In addition theoretical calculations of performance at different densities have been performed with Cheetah 2.0.

The quality of the casted test items with regard to density is variable. Most items have a density of 97$\pm$2 % of TMD. X-ray images of the cylindrical charges show lower density in the upper part of the charges than at the bottom. In addition the casted items contain some bubbles also mostly in the upper part of the charges. The casting process has large potential for improvement.

Critical diameter for MCX-8100 Lot DDP13A0002E seems to be relatively reproducible. 4 test items have been tested giving a critical diameter of 19.7 mm. The detonation stops in the cylindrical charge having diameter from 19.8 and 19.6 mm.

Detonation velocities have been determined for cylindrical charges with diameter 36$\pm$1 mm. Detonation velocity vary with the density of the charges. Average detonation velocity for 4 tested items with average density 1.72$\pm$0.02 g/cm^3 is 7106$\pm$148 m/s. This result is 3-400 m/s below the theoretically calculated value with Cheetah 2.0

Detonation pressure determined by Plate Dent test for 2 test charges gives an average pressure of 208 kbar. As for the detonation velocity this result is below the theoretically calculated value by Cheetah 2.0. The difference is in order of 20$\pm$10 kbar.

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Appendix A Certificate Plate Dent Plates

The certificate for the steel used as witness plate in the Plate Dent test is given below.

Item #	Charge #	Lot	Piece ID	Cust.art.#	Art #	Qty	Description
	16348				200480	1	Rundtstål S355J2/520M

RUUKKI

OVAKO IMATRA

Inspection certificate EN 10204 3.2 DNV 1/ 2

26.9.2013 357406 DNV HEL 13-2183

Customer's order number W2270	Manufacturer's order number 100721 3
Customer/consignee Ruukki Norge A/S Prof. Birkelandsvei 21 1062 Oslo Norway	Buyer Ruukki Norge A/S Postboks 140 Furuset 1001 Oslo Norway
Customer reference number RUUKKI NORGE W2270	
Product Round bar As rolled Hot rolled, reeled	Steel grade S355J2/520M Specification EN10025-2:2004/IS2721.01.

Charge	Diameter/dimensions	Reduction ratio	Weight
16348	160 mm	5,71	7 880 KG

CAST ANALYSIS

	C	SI	MN	P	S	CR	NI	MO
	%	%	%	%	%	%	%	%
Min					0,020			
Result	0,12	0,33	1,24	0,018	0,029	0,20	0,15	0,03
Max	0,20	0,55	1,60	0,025	0,040			

	V	CU	CEV
	%	%	%
Min			
Result	0,06	0,23	0,41
Max	0,09	0,30	0,54

CHARPY V2/-20 C (J)

	KV1	KV2	KV3	KV AVER
	J	J	J	J
Min				27
Result	65	100	105	90
Max				

TENSILE TEST FROM 1/3 RADIUS

	REH	RM	A 5	Z
	MPa	MPa	%	%
Min	350	490	20,0	
Result	403	548	24,6	57
Max		630		

The products supplied are in compliance with the requirements of the order

The coverage and the acceptance criteria of the UT of the bars fulfils the requirements of SEP 1920 coverage 1/quality class A.

Ovako Imatra Oy Ab
Quality control
FI-55100 Imatra
Tel. +358 (0)5 68021
Fax. +358 (0)5 6802 211

Ovako Imatra Oy Ab
Teollisuuskuja 1
FI-14200 Turenki
Tel. +358 (0)5 68021
Fax. +358 (0)3 6334032

Certified Quality System to
ISO/TS 16949 by DNV
Business ID 2067276-0
Domicile Imatra

OVAKO
IMATRA

Inspection certificate **EN 10204 3.2 DNV** **2/ 2**

26.9.2013 **357406** **DNV HEL 13-2183**

Customer's order number W2270	Manufacturer's order number 100721 3
Customer/consignee Ruukki Norge A/S Prof. Birkelandsvei 21 1062 Oslo Norway	Buyer Ruukki Norge A/S Postboks 140 Furuset 1001 Oslo Norway
Customer reference number RUUKKI NORGE W2270	
Product Round bar As rolled Hot rolled, reeled	Steel grade S355J2/520M Specification EN10025-2:2004/IS2721.01.

Charge	Diameter/dimensions	Reduction ratio	Weight
16348	160 mm	5,71	7 880 KG

The bundle labels are stamped

One end of each bar is hardstamped with cast number 16348
This is to certify that the material described above has been manufactured in conformance with the steel grade and specification mentioned on this inspection certificate and has been tested with satisfactory result according to requirement.
This certificate is issued by the manufacturer under the authorization of the Manufacturing Survey Arrangement No. R-1448, with Det Norske Veritas which is controlled by regular auditing.

Rolled steel bars used as substitute for forgings. Rules for Classification of Ships Pt. 2 Ch. 2 Sec.5.

Ovako Imatra Oy Ab
Matti Happonen
Authorized Inspector
Quality Control Laboratory

For certification/MSA
Ilpo Lehtola
Station Manager,Helsinki Office

DET NORSKE VERITAS ESTABLISHED 1864
MSA R-1447

Ovako Imatra Oy Ab Quality control FI-55100 Imatra Tel. +358 (0)5 68021	Ovako Imatra Oy Ab Teollisuuskuja 1 FI-14200 Turenki Tel. +358 (0)5 68021	Certified Quality System to ISO/TS 16949 by DNV Business ID 2067276-0 Domicile Imatra

Appendix B Control report HWC

Figure B.1 shows the control report for the HWC composition used to press boosters for initiation of the different test items. The applied HWC was manufactured by Chemring Nobel.

KONTROLLRAPPORT B
etter EN 10204 - 3.1

Chemring Nobel

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

Kjersti K Bersantse
Kvalitetssjef

Chemring Nobel AS
High Energy Materials
Manager QA

Figure B.1 Control report for the HWC composition used in applied boosters.

Appendix C Cheetah calculations MCX-8100

C.1 BKWC Product Library

C.1.1 TMD 1.765 g/cm^3

```
Product library title: bkwc
Reactant library title: # Version 2.0 by P. Clark Souers

The composition:
Name       % wt.   % mol  % vol    Heat of      Mol.    TMD
                                   formation    wt.     (g/cc)
                                   (cal/mol)
nto        53.00  65.23  48.98   -24140   130.07     1.91 c2h2n4o3
dnan24     35.00  28.28  39.91   -44455   198.13     1.55 c7h6n2o5
hmx        12.00   6.49  11.12    17866   296.17     1.91 c4h8n8o8

Density  =  1.7650 g/cc   Mixture TMD =  1.7650 g/cc   % TMD = 100.0000

The C-J condition:
The pressure          =          24.19 GPa
The volume            =          0.433 cc/g
The density           =          2.312 g/cc
The energy            =           2.86 kJ/cc explosive
The temperature       =           3367 K
The shock velocity    =          7.612 mm/us
The particle velocity =          1.801 mm/us
The speed of sound    =          5.811 mm/us
Gamma                 =          3.227

Cylinder runs:                % of standards
  V/V0     Energy    TATB     PETN      HMX     CL-20   TRITON
 (rel.)   (kJ/cc)  1.83g/cc 1.76g/cc 1.89g/cc 2.04g/cc 1.70g/cc
   1.00    -0.85
   2.20    -4.66      96       73       62       51      107
   4.10    -5.60      96       73       63       53      102
   6.50    -6.01      97       72       64       54       98
  10.00    -6.29      97       72       64       55       96
  20.00    -6.63      97       72       65       56       93
  40.00    -6.89      96       73       66       57       89
  80.00    -7.10      96       73       66       57       86
 160.00    -7.27

Freezing occurred at T =     1800.0 K and relative V =   1.728
The mechanical energy of detonation =      -7.543 kJ/cc
The thermal energy of detonation    =      -0.000 kJ/cc
The total energy of detonation      =      -7.543 kJ/cc

JWL Fit results:
E0    =       -7.878 kJ/cc
A     =       805.71 GPa, B     =       7.29 GPa,  C     =         1.20 GPa
R[1] =          4.86,     R[2] =       1.10,      omega =         0.34
RMS fitting error =   0.65 %
```

C.1.2 Density 1.750 g/cm^3

```
Product library title: bkwc
Reactant library title: # Version 2.0 by P. Clark Souers
```

```
The composition:
Name      % wt.   % mol  % vol    Heat of     Mol.   TMD
                               formation     wt.    (g/cc)
                               (cal/mol)
nto        53.00  65.23  48.98   -24140   130.07     1.91 c2h2n4o3
dnan24     35.00  28.28  39.91   -44455   198.13     1.55 c7h6n2o5
hmx        12.00   6.49  11.12    17866   296.17     1.91 c4h8n8o8

Density  =  1.7500 g/cc   Mixture TMD =  1.7650 g/cc   % TMD = 99.1510

The C-J condition:
The pressure          =          23.65 GPa
The volume            =          0.436 cc/g
The density           =          2.292 g/cc
The energy            =           2.80 kJ/cc explosive
The temperature       =           3372 K
The shock velocity    =          7.560 mm/us
The particle velocity =          1.788 mm/us
The speed of sound    =          5.772 mm/us
Gamma                 =          3.229

Cylinder runs:             % of standards
  V/V0     Energy    TATB     PETN      HMX    CL-20   TRITON
 (rel.)   (kJ/cc)  1.83g/cc 1.76g/cc 1.89g/cc 2.04g/cc 1.70g/cc
   1.00    -0.83
   2.20    -4.58      94       72       61       51      105
   4.10    -5.52      95       72       62       52      100
   6.50    -5.93      95       71       63       53       97
  10.00    -6.21      95       71       63       54       95
  20.00    -6.55      95       71       64       55       91
  40.00    -6.81      95       72       65       56       88
  80.00    -7.01      95       72       65       57       85
 160.00    -7.18

Freezing occurred at T =     1800.0 K and relative V =   1.738
The mechanical energy of detonation =     -7.456 kJ/cc
The thermal energy of detonation    =     -0.000 kJ/cc
The total energy of detonation      =     -7.456 kJ/cc

JWL Fit results:
E0   =       -7.790 kJ/cc
A    =       790.91 GPa, B    =      7.18 GPa,  C     =         1.19 GPa
R[1] =         4.87,     R[2] =      1.10,      omega =         0.34
RMS fitting error =   0.65 %
```

C.1.3 Density 1.740 g/cm^3

```
Product library title: bkwc
Reactant library title: # Version 2.0 by P. Clark Souers

The composition:
Name      % wt.   % mol  % vol    Heat of     Mol.   TMD
                               formation     wt.    (g/cc)
                               (cal/mol)
nto        53.00  65.23  48.98   -24140   130.07     1.91 c2h2n4o3
```

```
dnan24     35.00  28.28  39.91   -44455   198.13     1.55 c7h6n2o5
hmx        12.00   6.49  11.12    17866   296.17     1.91 c4h8n8o8

Density  =  1.7400 g/cc   Mixture TMD =  1.7650 g/cc   % TMD = 98.5844

The C-J condition:
The pressure          =          23.29 GPa
The volume            =          0.439 cc/g
The density           =          2.279 g/cc
The energy            =           2.75 kJ/cc explosive
The temperature       =           3374 K
The shock velocity    =          7.525 mm/us
The particle velocity =          1.779 mm/us
The speed of sound    =          5.746 mm/us
Gamma                 =          3.230

Cylinder runs:             % of standards
  V/V0     Energy    TATB     PETN      HMX    CL-20   TRITON
 (rel.)   (kJ/cc)  1.83g/cc 1.76g/cc 1.89g/cc 2.04g/cc 1.70g/cc
   1.00    -0.82
   2.20    -4.53      93       71       61       50      104
   4.10    -5.47      94       71       62       52       99
   6.50    -5.87      94       71       62       53       96
  10.00    -6.15      94       71       63       54       94
  20.00    -6.49      94       71       64       55       91
  40.00    -6.75      94       71       64       56       87
  80.00    -6.96      94       71       65       56       84
 160.00    -7.12

Freezing occurred at T =     1800.0 K and relative V =   1.745
The mechanical energy of detonation =     -7.398 kJ/cc
The thermal energy of detonation    =     -0.000 kJ/cc
The total energy of detonation      =     -7.398 kJ/cc

JWL Fit results:
E0   =       -7.814 kJ/cc
A    =       783.86 GPa, B    =     7.13 GPa,  C     =        1.05 GPa
R[1] =         4.87,     R[2] =     1.06,      omega =        0.31
RMS fitting error =   0.87 %
```

C.1.4 Density 1.730 g/cm^3

```
Product library title: bkwc
Reactant library title: # Version 2.0 by P. Clark Souers

The composition:
Name      % wt.   % mol  % vol    Heat of     Mol.    TMD
                                 formation    wt.     (g/cc)
                                 (cal/mol)
nto        53.00  65.23  48.98   -24140   130.07     1.91 c2h2n4o3
dnan24     35.00  28.28  39.91   -44455   198.13     1.55 c7h6n2o5
hmx        12.00   6.49  11.12    17866   296.17     1.91 c4h8n8o8

Density  =  1.7300 g/cc   Mixture TMD =  1.7650 g/cc   % TMD = 98.0179

The C-J condition:
```

```
The pressure          =          22.94 GPa
The volume            =          0.441 cc/g
The density           =          2.265 g/cc
The energy            =           2.71 kJ/cc explosive
The temperature       =           3377 K
The shock velocity    =          7.490 mm/us
The particle velocity =          1.770 mm/us
The speed of sound    =          5.720 mm/us
Gamma                 =          3.231

Cylinder runs:             % of standards
  V/V0     Energy    TATB     PETN      HMX    CL-20   TRITON
 (rel.)   (kJ/cc)  1.83g/cc 1.76g/cc 1.89g/cc 2.04g/cc 1.70g/cc
   1.00    -0.81
   2.20    -4.48      92       71       60       50      103
   4.10    -5.41      93       70       61       51       98
   6.50    -5.82      93       70       62       52       95
  10.00    -6.10      93       70       62       53       93
  20.00    -6.43      94       70       63       54       90
  40.00    -6.69      94       70       64       55       87
  80.00    -6.90      94       71       64       56       84
 160.00    -7.07

Freezing occurred at T =     1800.0 K and relative V =   1.752
The mechanical energy of detonation =     -7.340 kJ/cc
The thermal energy of detonation    =     -0.000 kJ/cc
The total energy of detonation      =     -7.340 kJ/cc

JWL Fit results:
E0   =       -7.673 kJ/cc
A    =       770.66 GPa, B    =      7.02 GPa,  C     =         1.19 GPa
R[1] =         4.88,     R[2] =      1.10,      omega =         0.34
RMS fitting error =   0.66 %
```

C.1.5 Density 1.720 g/cm^3

```
Product library title: bkwc
Reactant library title: # Version 2.0 by P. Clark Souers

The composition:
Name      % wt.   % mol  % vol    Heat of     Mol.   TMD
                                 formation     wt.    (g/cc)
                                 (cal/mol)
nto        53.00  65.23  48.98   -24140   130.07     1.91 c2h2n4o3
dnan24     35.00  28.28  39.91   -44455   198.13     1.55 c7h6n2o5
hmx        12.00   6.49  11.12    17866   296.17     1.91 c4h8n8o8

Density  =  1.7200 g/cc   Mixture TMD =  1.7650 g/cc   % TMD = 97.4513

The C-J condition:
The pressure          =          22.59 GPa
The volume            =          0.444 cc/g
The density           =          2.252 g/cc
The energy            =           2.67 kJ/cc explosive
The temperature       =           3379 K
```

```
The shock velocity    =          7.455 mm/us
The particle velocity =          1.762 mm/us
The speed of sound    =          5.693 mm/us
Gamma                 =          3.232

Cylinder runs:             % of standards
  V/V0     Energy    TATB     PETN      HMX    CL-20   TRITON
 (rel.)   (kJ/cc)  1.83g/cc 1.76g/cc 1.89g/cc 2.04g/cc 1.70g/cc
   1.00    -0.80
   2.20    -4.43      91       70       59       49      102
   4.10    -5.36      92       69       61       51       97
   6.50    -5.76      93       69       61       52       94
  10.00    -6.04      93       70       62       53       92
  20.00    -6.38      93       70       63       54       89
  40.00    -6.63      93       70       63       55       86
  80.00    -6.84      93       70       64       55       83
 160.00    -7.01

Freezing occurred at T =     1800.0 K and relative V =   1.759
The mechanical energy of detonation =     -7.283 kJ/cc
The thermal energy of detonation    =     -0.000 kJ/cc
The total energy of detonation      =     -7.283 kJ/cc

JWL Fit results:
E0   =       -7.695 kJ/cc
A    =       764.13 GPa, B    =      7.01 GPa,  C     =         1.05 GPa
R[1] =         4.88,     R[2] =      1.06,      omega =         0.31
RMS fitting error =   0.87 %
```

C.1.6 Density 1.710 g/cm^3

```
Product library title: bkwc
Reactant library title: # Version 2.0 by P. Clark Souers

The composition:
Name      % wt.   % mol  % vol    Heat of     Mol.   TMD
                                 formation     wt.    (g/cc)
                                 (cal/mol)
nto        53.00  65.23  48.98   -24140   130.07     1.91 c2h2n4o3
dnan24     35.00  28.28  39.91   -44455   198.13     1.55 c7h6n2o5
hmx        12.00   6.49  11.12    17866   296.17     1.91 c4h8n8o8
Density  =  1.7100 g/cc   Mixture TMD =  1.7650 g/cc   % TMD = 96.8847

The C-J condition:
The pressure          =          22.25 GPa
The volume            =          0.447 cc/g
The density           =          2.239 g/cc
The energy            =           2.63 kJ/cc explosive
The temperature       =           3382 K
The shock velocity    =          7.420 mm/us
The particle velocity =          1.753 mm/us
The speed of sound    =          5.667 mm/us
Gamma                 =          3.232

Cylinder runs:             % of standards
  V/V0     Energy    TATB     PETN      HMX    CL-20   TRITON
```

```
 (rel.)   (kJ/cc)  1.83g/cc 1.76g/cc 1.89g/cc 2.04g/cc 1.70g/cc
   1.00    -0.79
   2.20    -4.38      90       69       59       48      101
   4.10    -5.31      91       69       60       50       96
   6.50    -5.71      92       69       61       51       93
  10.00    -5.98      92       69       61       52       91
  20.00    -6.32      92       69       62       53       88
  40.00    -6.58      92       69       63       54       85
  80.00    -6.78      92       69       63       55       82
 160.00    -6.95

Freezing occurred at T =     1800.0 K and relative V =   1.766
The mechanical energy of detonation =     -7.225 kJ/cc
The thermal energy of detonation    =     -0.000 kJ/cc
The total energy of detonation      =     -7.225 kJ/cc

JWL Fit results:
E0   =       -7.555 kJ/cc
A    =       749.96 GPa, B    =      6.86 GPa,  C     =         1.18 GPa
R[1] =         4.88,     R[2] =      1.10,      omega =         0.34
RMS fitting error =   0.67 %
```

C.2 BKWS Product Library

C.2.1 TMD 1.765 g/cm^3

```
Product library title: bkws library
Reactant library title: # Version 2.0 by P. Clark Souers

The composition:
Name      % wt.   % mol  % vol    Heat of     Mol.   TMD
                                 formation     wt.    (g/cc)
                                 (cal/mol)
nto        53.00  65.23  48.98   -24140   130.07     1.91 c2h2n4o3
dnan24     35.00  28.28  39.91   -44455   198.13     1.55 c7h6n2o5
hmx        12.00   6.49  11.12    17866   296.17     1.91 c4h8n8o8

Density  =  1.7650 g/cc   Mixture TMD =  1.7650 g/cc   % TMD = 100.0000

The C-J condition:
The pressure          =          24.43 GPa
The volume            =          0.437 cc/g
The density           =          2.290 g/cc
The energy            =           2.80 kJ/cc explosive
The temperature       =           3385 K
The shock velocity    =          7.770 mm/us
The particle velocity =          1.781 mm/us
The speed of sound    =          5.988 mm/us
Gamma                 =          3.362

Cylinder runs:             % of standards
  V/V0     Energy    TATB     PETN      HMX    CL-20   TRITON
 (rel.)   (kJ/cc)  1.83g/cc 1.76g/cc 1.89g/cc 2.04g/cc 1.70g/cc
   1.00    -0.87
   2.20    -4.86     100       76       65       54      111
   4.10    -5.84     100       76       66       55      106
   6.50    -6.25     100       75       66       56      102
```

10.00	-6.53	100	75	67	57	100
20.00	-6.87	100	75	67	58	96
40.00	-7.12	100	75	68	59	92
80.00	-7.32	99	75	68	59	89
160.00	-7.49					

```
Freezing occurred at T =     1800.0 K and relative V =   1.740
The mechanical energy of detonation =     -7.757 kJ/cc
The thermal energy of detonation    =     -0.000 kJ/cc
The total energy of detonation      =     -7.757 kJ/cc

JWL Fit results:
E0   =       -8.067 kJ/cc
A    =       942.36 GPa, B    =         8.07 GPa,  C     =      1.20 GPa
R[1] =         5.00,     R[2] =         1.10,      omega =      0.35
RMS fitting error =   0.85 %
```

C.2.2 Density 1.750 g/cm^3

```
Product library title: bkws library
Reactant library title: # Version 2.0 by P. Clark Souers

The composition:
```

Name	% wt.	% mol	% vol	Heat of formation (cal/mol)	Mol. wt.	TMD (g/cc)	
nto	53.00	65.23	48.98	-24140	130.07	1.91	c2h2n4o3
dnan24	35.00	28.28	39.91	-44455	198.13	1.55	c7h6n2o5
hmx	12.00	6.49	11.12	17866	296.17	1.91	c4h8n8o8

```
Density  =  1.7500 g/cc   Mixture TMD =  1.7650 g/cc   % TMD = 99.1510

The C-J condition:
The pressure          =          23.91 GPa
The volume            =          0.440 cc/g
The density           =          2.272 g/cc
The energy            =           2.75 kJ/cc explosive
The temperature       =           3391 K
The shock velocity    =          7.712 mm/us
The particle velocity =          1.771 mm/us
The speed of sound    =          5.941 mm/us
Gamma                 =          3.354

Cylinder runs:               % of standards
```

V/V0 (rel.)	Energy (kJ/cc)	TATB 1.83g/cc	PETN 1.76g/cc	HMX 1.89g/cc	CL-20 2.04g/cc	TRITON 1.70g/cc
1.00	-0.85					
2.20	-4.78	99	75	64	53	110
4.10	-5.75	99	75	65	54	104
6.50	-6.17	99	74	65	55	101
10.00	-6.45	99	74	66	56	98
20.00	-6.78	99	74	67	57	95
40.00	-7.04	98	74	67	58	91
80.00	-7.24	98	74	68	59	88
160.00	-7.40					

```
Freezing occurred at T =     1800.0 K and relative V =   1.751
The mechanical energy of detonation =     -7.673 kJ/cc
The thermal energy of detonation    =     -0.000 kJ/cc
The total energy of detonation      =     -7.673 kJ/cc
```

```
JWL Fit results:
E0   =       -8.071 kJ/cc
A    =       903.20 GPa, B    =      7.75 GPa , C     =         1.04 GPa
R[1] =         4.96,     R[2] =      1.06,      omega =         0.31
RMS fitting error =   1.06 %
```

C.2.3 Density 1.740 g/cm^3

```
Product library title: bkws library
Reactant library title: # Version 2.0 by P. Clark Souers
```

The composition:

Name	% wt.	% mol	% vol	Heat of formation (cal/mol)	Mol. wt.	TMD (g/cc)	
nto	53.00	65.23	48.98	-24140	130.07	1.91	c2h2n4o3
dnan24	35.00	28.28	39.91	-44455	198.13	1.55	c7h6n2o5
hmx	12.00	6.49	11.12	17866	296.17	1.91	c4h8n8o8

```
Density  =  1.7400 g/cc   Mixture TMD =  1.7650 g/cc   % TMD = 98.5844

The C-J condition:
The pressure          =          23.57 GPa
The volume            =          0.443 cc/g
The density           =          2.260 g/cc
The energy            =           2.71 kJ/cc explosive
The temperature       =           3395 K
The shock velocity    =          7.674 mm/us
The particle velocity =          1.765 mm/us
The speed of sound    =          5.909 mm/us
Gamma                 =          3.348
```

Cylinder runs: % of standards

V/V0 (rel.)	Energy (kJ/cc)	TATB 1.83g/cc	PETN 1.76g/cc	HMX 1.89g/cc	CL-20 2.04g/cc	TRITON 1.70g/cc
1.00	-0.84					
2.20	-4.73	98	74	63	52	108
4.10	-5.70	98	74	64	54	103
6.50	-6.11	98	74	65	55	100
10.00	-6.39	98	74	65	56	97
20.00	-6.73	98	73	66	57	94
40.00	-6.98	98	73	67	57	90
80.00	-7.18	97	73	67	58	87
160.00	-7.34					

```
Freezing occurred at T =     1800.0 K and relative V =   1.759
The mechanical energy of detonation =     -7.616 kJ/cc
The thermal energy of detonation    =     -0.000 kJ/cc
The total energy of detonation      =     -7.616 kJ/cc

JWL Fit results:
E0   =       -8.014 kJ/cc
A    =       886.20 GPa, B    =     7.66 GPa,  C     =         1.04 GPa
R[1] =         4.96,     R[2] =     1.05,      omega =         0.31
RMS fitting error =   1.06 %
```

C.2.4 Density 1.730 g/cm^3

```
Product library title: bkws library
Reactant library title: # Version 2.0 by P. Clark Souers
```

```
The composition:
Name      % wt.   % mol  % vol    Heat of     Mol.   TMD
                                formation     wt.    (g/cc)
                                (cal/mol)
nto         53.00  65.23  48.98   -24140   130.07     1.91 c2h2n4o3
dnan24      35.00  28.28  39.91   -44455   198.13     1.55 c7h6n2o5
hmx         12.00   6.49  11.12    17866   296.17     1.91 c4h8n8o8
Density  =  1.7300 g/cc   Mixture TMD =  1.7650 g/cc   % TMD = 98.0179

The C-J condition:
The pressure          =          23.23 GPa
The volume            =          0.445 cc/g
The density           =          2.248 g/cc
The energy            =           2.68 kJ/cc explosive
The temperature       =           3399 K
The shock velocity    =          7.635 mm/us
The particle velocity =          1.759 mm/us
The speed of sound    =          5.877 mm/us
Gamma                 =          3.342


Cylinder runs:             % of standards
  V/V0     Energy    TATB     PETN      HMX    CL-20   TRITON
 (rel.)   (kJ/cc)  1.83g/cc 1.76g/cc 1.89g/cc 2.04g/cc 1.70g/cc
   1.00    -0.83
   2.20    -4.68      96        74       63       52      107
   4.10    -5.64      97        73       64       53      102
   6.50    -6.05      97        73       64       54       99
  10.00    -6.33      97        73       65       55       97
  20.00    -6.67      97        73       65       56       93
  40.00    -6.92      97        73       66       57       90
  80.00    -7.12      97        73       67       58       86
 160.00    -7.29

Freezing occurred at T =     1800.0 K and relative V =   1.767
The mechanical energy of detonation =     -7.560 kJ/cc
The thermal energy of detonation    =     -0.000 kJ/cc
The total energy of detonation      =     -7.560 kJ/cc

JWL Fit results:
E0   =       -7.956 kJ/cc
A    =       869.35 GPa, B    =      7.57 GPa,  C     =         1.04 GPa
R[1] =         4.96,     R[2] =      1.05,      omega =         0.31
RMS fitting error =   1.06 %
```

C.2.5 Density 1.720 g/cm^3

```
Product library title: bkws library
Reactant library title: # Version 2.0 by P. Clark Souers

The composition:
Name      % wt.   % mol  % vol    Heat of     Mol.   TMD
                                formation     wt.    (g/cc)
                                (cal/mol)
nto         53.00  65.23  48.98   -24140   130.07     1.91 c2h2n4o3
dnan24      35.00  28.28  39.91   -44455   198.13     1.55 c7h6n2o5
hmx         12.00   6.49  11.12    17866   296.17     1.91 c4h8n8o8
Density  =  1.7200 g/cc   Mixture TMD =  1.7650 g/cc   % TMD = 97.4513

The C-J condition:
The pressure          =          22.90 GPa
```

```
The volume             =          0.447 cc/g
The density            =          2.236 g/cc
The energy             =           2.64 kJ/cc explosive
The temperature        =           3403 K
The shock velocity     =          7.597 mm/us
The particle velocity =           1.752 mm/us
The speed of sound     =          5.845 mm/us
Gamma                  =          3.336


Cylinder runs:              % of standards
  V/V0     Energy    TATB     PETN      HMX    CL-20   TRITON
 (rel.)   (kJ/cc)  1.83g/cc 1.76g/cc 1.89g/cc 2.04g/cc 1.70g/cc
   1.00    -0.82
   2.20    -4.63      95       73       62       51      106
   4.10    -5.59      96       72       63       53      101
   6.50    -6.00      96       72       64       54       98
  10.00    -6.28      96       72       64       55       96
  20.00    -6.61      96       72       65       56       92
  40.00    -6.86      96       72       65       56       89
  80.00    -7.07      96       72       66       57       86
 160.00    -7.23

Freezing occurred at T =     1800.0 K and relative V =   1.774
The mechanical energy of detonation =     -7.503 kJ/cc
The thermal energy of detonation    =     -0.000 kJ/cc
The total energy of detonation      =     -7.503 kJ/cc

JWL Fit results:
E0   =       -7.898 kJ/cc
A    =       852.70 GPa, B    =     7.49 GPa, C     =         1.04 GPa
R[1] =         4.96,     R[2] =     1.05,     omega =         0.31
RMS fitting error =   1.06 %
```

C.2.6 Density 1.710 g/cm^3

```
Product library title: bkws library
Reactant library title: # Version 2.0 by P. Clark Souers

The composition:
Name      % wt.   % mol  % vol    Heat of     Mol.   TMD
                                 formation     wt.    (g/cc)
                                 (cal/mol)
nto        53.00  65.23  48.98   -24140   130.07     1.91 c2h2n4o3
dnan24     35.00  28.28  39.91   -44455   198.13     1.55 c7h6n2o5
hmx        12.00   6.49  11.12    17866   296.17     1.91 c4h8n8o8

Density  =  1.7100 g/cc   Mixture TMD =  1.7650 g/cc   % TMD = 96.8847

The C-J condition:
The pressure           =          22.57 GPa
The volume             =          0.450 cc/g
The density            =          2.224 g/cc
The energy             =           2.61 kJ/cc explosive
The temperature        =           3406 K
The shock velocity     =          7.559 mm/us
The particle velocity =           1.746 mm/us
The speed of sound     =          5.813 mm/us
Gamma                  =          3.330
```

Cylinder runs: % of standards

V/V0 (rel.)	Energy (kJ/cc)	TATB 1.83g/cc	PETN 1.76g/cc	HMX 1.89g/cc	CL-20 2.04g/cc	TRITON 1.70g/cc
1.00	-0.81					
2.20	-4.58	94	72	61	51	105
4.10	-5.54	95	72	62	52	100
6.50	-5.94	95	72	63	53	97
10.00	-6.22	95	72	64	54	95
20.00	-6.55	95	72	64	55	91
40.00	-6.81	95	72	65	56	88
80.00	-7.01	95	72	65	57	85
160.00	-7.17					

```
Freezing occurred at T =     1800.0 K and relative V =   1.782
The mechanical energy of detonation =     -7.447 kJ/cc
The thermal energy of detonation    =     -0.000 kJ/cc
The total energy of detonation      =     -7.447 kJ/cc

JWL Fit results:
E0   =       -7.751 kJ/cc
A    =       854.19 GPa, B    =      7.66 GPa, C     =         1.19 GPa
R[1] =         5.00,     R[2] =      1.10,     omega =         0.35
RMS fitting error =   0.85 %
```