FFI-rapport 2015/02323

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2 december 2015

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120503

P: ISBN 978-82-464-2700-3
E: ISBN 978-82-464-2701-0

Keywords

Detonasjon

Trykkmåling

Hastighet

Testing

Sprengstoffer

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English summary

Independent of the application of an explosive composition there are certain properties that are important to know. Performance depends on properties as detonation velocity and detonation pressure. Sensitivity of munitions depend on properties such as critical diameter to fulfil IM requirements. MCX-6100 is one of the new compositions developed with large critical diameter to withstand shock threat in the form of Bullet Attack, Fragment Impact, Sympathetic Reaction or Shape Charged Jet Attack.

MCX-6100 is a composition developed and produced by Chemring Nobel. It is a melt-cast composition with potential application as filling in large calibre like 120 mm and 155 mm shells. We have characterized MCX-6100 due to the potential for utilisation in these ammunition types. MCX-6100 has DNAN as binder. The solid filler is a mix of NTO and RDX. Nominal content for MCX-6100 is 53/32/15 (NTO/DNAN/RDX). Selecting DNAN as binder makes it possible to use the same filling plants as for TNT or TNT based compositions to fill MCX-6100 into warheads.

Different samples of MCX-6100 have 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 obtained quality of the casted test items with regard to density of the fillings has variations. Most items have a density of 96±2 % of Theoretical Maximum Density (TMD). X-ray images of cylindrical charges show lower density in the upper part of the charges than in the bottom. In addition the casted items contain some bubbles, also mostly in the upper part of the charges. The applied casting process has indisputable potential for improvement.

Measurements of critical diameter for MCX-6100 CH 6079/13 seem relatively reproducible. 5 conical charges have been tested giving a critical diameter of 19.1± 1.4 mm or 19.7 ± 0.8 mm if the 4 most equal results are considered.

Detonation velocity has been determined for both cylindrical charges with diameter 36±1 mm and for conical charges with largest diameter 30 mm. Detonation velocity varied with density of the test items. The average detonation velocity for 4 cylindrical test items having an average density of 1.71±0.02 g/cm^3 was measured to be 7199±81 m/s. This result is 3-400 m/s lower than the theoretical calculated value with Cheetah 2.0. For the conical charge the detonation velocity between charge diameter 27 mm and 24 mm was measured to be 6281 m/s and for charge diameter between 24 mm and 21 mm to be 4685 m/s.

Detonation pressure determined by the Plate Dent test for 6 test charges was measured to 190± 7 kbars. As for the detonation velocity this result is lower than the theoretical calculated value by Cheetah 2.0. The difference is 30±10 kbar.

Sammendrag

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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 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 is to obtain coated nitramines or press granules with properties suitable for press filling of munitions units or production of pressed charges.

Norway was the only country that used the energetic binder for explosive charges. Italy and Germany used their own 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 fillings for shaped charges.

To broaden the number of different compositions included in WP 4000 - generic fragmentation testing of 40 mm shells, 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, while 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 (Defence Science and Technology Organization) (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 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 MCX-6100 has been characterized with regard to critical diameter, detonation velocity and detonation pressure. MCX-6100 contains DNAN as binder and the filler is NTO/RDX. Nominal content of MCX-6100 is 53/32/15 (NTO/ DNAN/RDX). This composition has NTO/RDX content in the same range as the DNAN based US composition IMX-104 (53/31.7/15.3) (3) and the TNT based Chemring MCX-6002 composition (2).

Critical diameter has been determined by the use of conical charges and witness plates (9). In addition two conical charges were fitted with ionization pins to simultaneously measure detonation velocity. Detonation velocity was measured for cylindrical charges by the use of 4-6 ionization pins (10, 11). Detonation pressure was determined by use of the Plate Dent test (12, 13).

2 Experiments

2.1 Casting

All tested samples in this report have been casted by Chemring Nobel at Sætre in Norway. The composition used was CH 6079/13. The conditions for casting test items for determination of detonation velocity and pressure are summarized in Table 2.1.

Cast No	Cast temperature (°C)	Conditioning in incubator after casting		Remarks	Number when X-rayed
		Dwell time (hours)	Temperature (°C)		
34.1/13	96-98	1	89/90	Empty mould was lubricated with silicon, preheated for 30 min at 89/90°C	6
34.2/13	96-98	1	89-90		5
35.1/13	100-102	1	100-102	Empty mould was lubricated with silicon, mould preheated for 30 min at 100/102°C	8
35.2/13	100-102	1	100-102		7
36.1/13	100-102	1	100-102	Empty mould preheated for 30 min at 100/102°C	4
36.2/13	100-102	1	100-102		1
37.1/13	100-102	2	100-102		2
37.2/13	100-102	2	100-102		3

Table 2.1 Casting conditions for MCX-6100 test items used for determination of detonation velocity and pressure.

After the dwell time in the incubator the casting moulds were taken out and left at room temperature to the next day. The casted test items were then released from the moulds and transferred to plastic bags.

2.2 X-ray

The quality of the casted items was checked through X-raying with a 320 kV apparatus at Nammo Raufoss. Figure 2.1 and 2.2 show pictures of the X-ray films. Figure 2.1 gives the pictures of 4 samples. All samples have some dark areas with lower density, and sample 2 and 4 have been broken. Samples No 2 – 4 all contain several pores.

Figure 2.2 shows the X-ray pictures of items No 5 to No 8. All items have dark areas of low density with a concentration at the top. In addition all items contain several pores of different sizes.

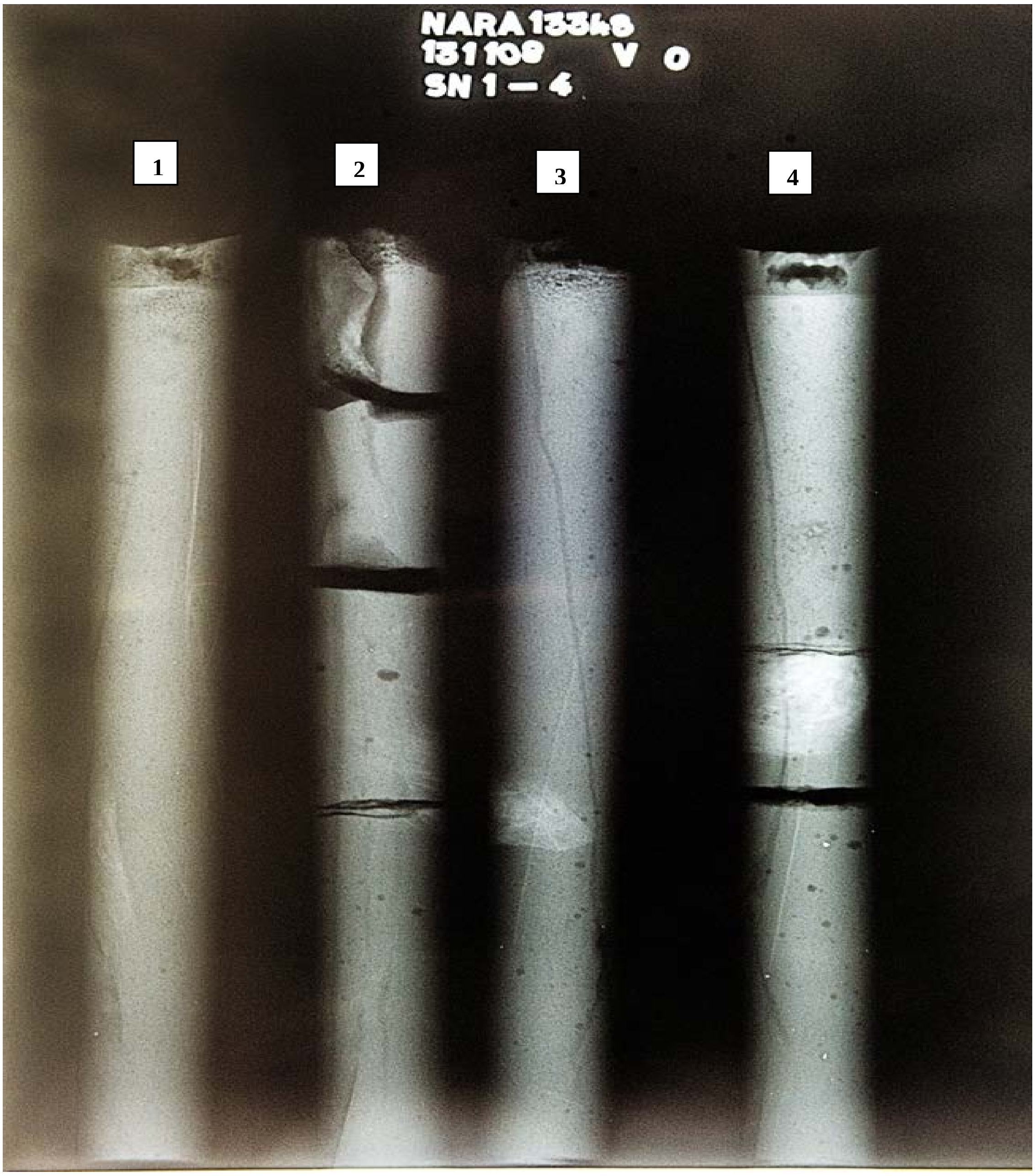

Figure 2.1 X-ray picture of tubes No 1 to No 4.

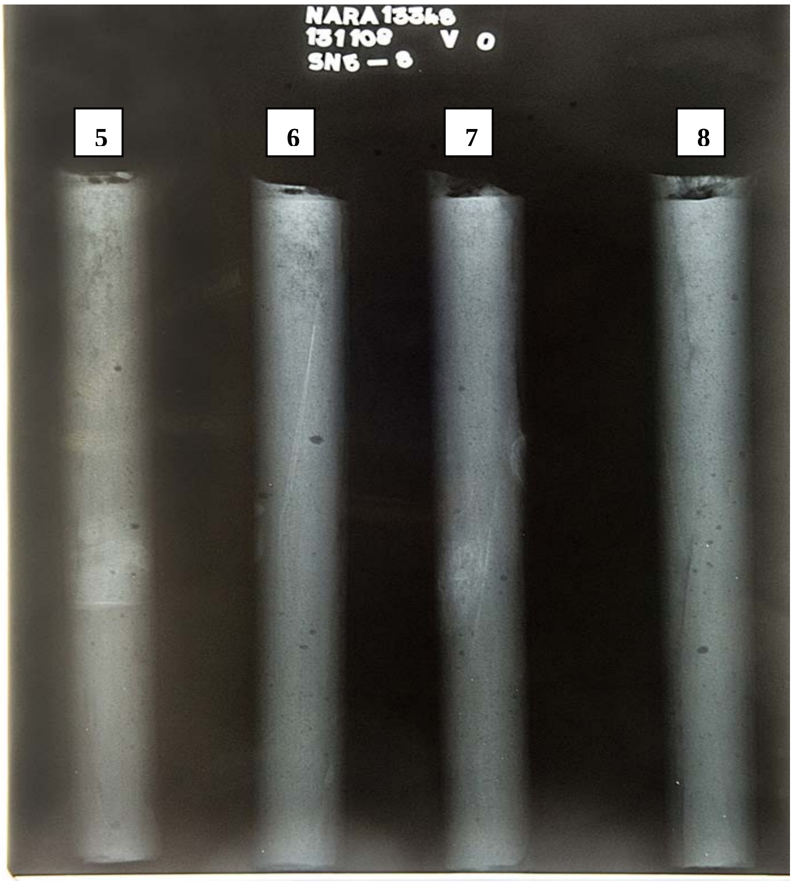

Figure 2.2 X-ray picture of tubes No 5 to No 8.

2.3 Critical diameter

2.3.1 Conical charge No1

The first conical charge we received from Chemring Nobel is shown in Figure 2.3.

Figure 2.3 Picture of the first conical charge after the booster had been glued to the top.

This conical charge had a diameter of 30 mm at the top and a length of 130 mm. The density had been determined by Chemring to 1.685 g/cm^3.

2.3.2 Conical charge No 2

Conical charge No 2 received from Chemring was cast 3/14 No 14.1. Pictures of the received item are shown in Figure 2.4. The conical charge had a diameter at the top of 30 mm and at the bottom of 10.8 mm. The weight was 113.68 g which gives an overall density of 1.687 g/cm^3.

Figure 2.4 Conical charge before and after it was released from the mould.

Figure 2.5 Test item after it was placed on the witness plate.

After the mould was removed a HWC booster was glued to the top. The complete test item was than attached to the witness plate by use of tape. In advance a copper wire was glued to the witness plate. Figure 2.5 shows the conical charge placed on the witness plate for testing.

2.3.3 Conical charge No 3

Conical charge No 3 contained cast 3/14 No 14.2. Figure 2.6 gives pictures of the received item, at the top in the mould and at the bottom after been released from the mould and placed on the witness plate for testing. The cone had a diameter at the top of 26.3 mm and at the bottom of 7.3 mm. The weight was 81.36 g which gives an overall density of 1.746 g/cm^3.

Figure 2.6 Test item in the mould (top) and on the witness plate with attached booster (bottom).

2.3.4 Conical charge No 4

The fourth conical charge containing MCX-6100 from CH 6079/13 and was cast No 16/14. A picture of the received item is shown in Figure 2.7. The length of the conical charge was 267 mm with a diameter of 30 mm at the top and 3.3 mm at the bottom. The weight was 118.28 g which gives an overall density of 1.676 g/cm^3.

Figure 2.7 Picture of conical charge No 4 after it was taken out of the mould.

This conical charge was instrumented with 4 ionization pins to measure detonation velocity before and after the expected critical diameter. Figure 2.8 gives a poor picture of the test item.

Figure 2.8 Conical charge cast 16/14 attached to the witness plate with ionization pins and booster.

2.3.5 Conical charge No 5

The fifth conical charge to be tested containing MCX-6100 from CH 6079/13 and was cast No 19/14. A picture of the item is shown in Figure 2.9. The conical charge had a diameter at the top of 30 mm and at the bottom of 7.0 mm. The weight was 117.65 g which gives an overall density of 1.685 g/cm^3.

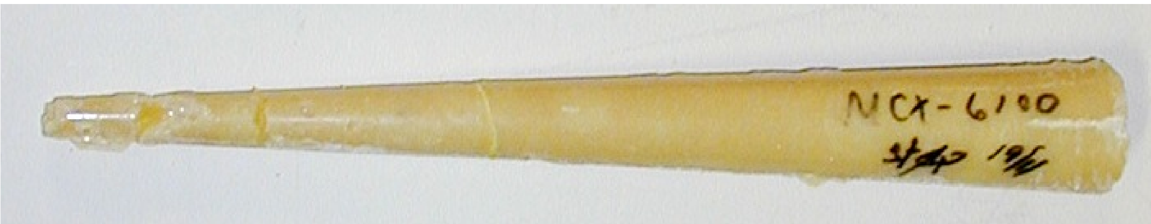

Figure 2.9 Conical charge No 5 cast 19/14 after it was released from the mould.

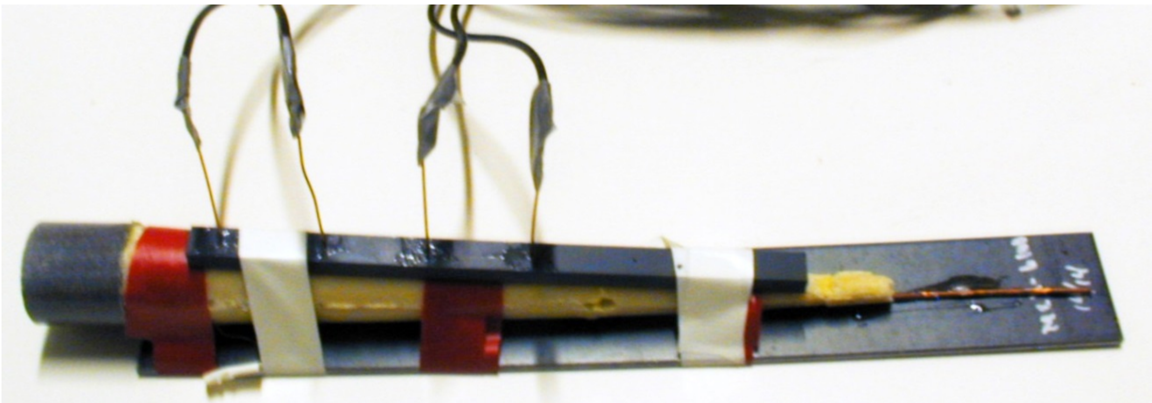

Figure 2.10 The conical charge after it was assembled on the witness plate and the ionization pins placed in correct positions

2.4 Detonation Velocity

6 of the 8 X-rayed cylindrical charges were corrected in a lathe to obtain plane surfaces both at the top and the bottom. The two broken samples were excluded. After this correction dimensions and weight were measured by Nammo Raufoss. The results are given in Table 2.2

No	**Diameter (mm)**		**Length (mm)**	**Weight (g)**	**Volume (cm^3)**	**Density (g/cm^3)**
	Top	Bottom				
1	38.0	35.0	275	500.0	287.65	1.74
3	38.0	35.1	278	507.6	290.79	1.74
5	38.0	35.0	283	490.2	296.02	1.66
6	38.0	35.1	280.5	496.4	293.40	1.70
7	38.0	35.0	281.5	496.6	294.45	1.69
8	38.0	48.8	278	495.2	289.30	1.71

Table 2.2 Properties of the test items casted for determination of detonation velocity and pressure.

5 of the items (No 1, 3, 6, 7 and 8) were tested at Bradalsmyra, Table 2.4. The last item, No 5 CH 6079/13 cast 34.2/13 with the lowest density, was taken to FFI for testing. This item contained silicon on the surface that was removed. The charge was then cut into three parts for determination of density before they were glued together. The central part of the original charge was selected as the bottom of the new test item (2-1-3). (Part 2: new bottom, Part 1: new middle and Part 3: new top). The different parts have different densities, Table 2.3. The obtained densities may indicate that sedimentation during casting had taken place. In addition, as the X-ray film shows, the item has pores, voids and area of reduced density.

 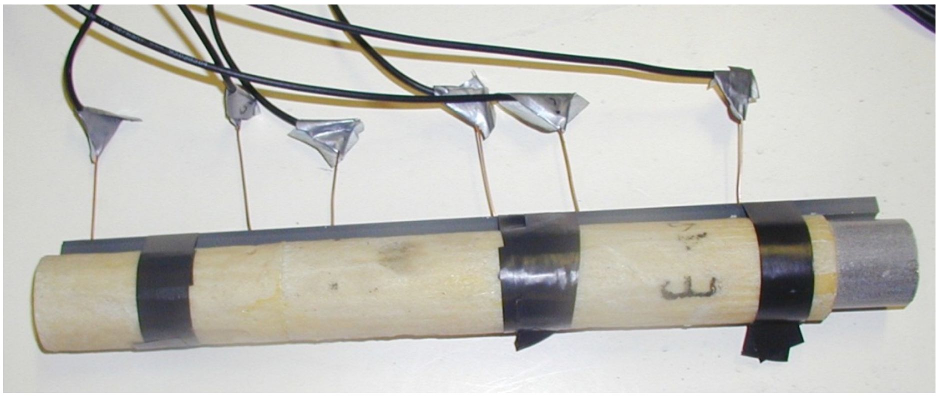

Figure 2.11 Charge No 5 before it was divided (to the left) and after it was glued together and fitted with ionization pins (right).

Charge	Weight (g)	Diameter (mm)		Average Radius (mm)	Height (mm)	Volume (cm^3)	Density (g/cm^3)
		Top	Bottom				
original	489.97	37.85	34.6	18.1125	283	291.67	1.680
1	143.32	34.7	35.2	17.4750	84.3	80.87	1.772
2	139.62	35.2	36.03	17.8075	82.4	82.09	1.701
3	200.28	36.2	37.85	18.5125	112.3	120.91	1.656

Table 2.3 Properties of the cast No 5 before and after it was divided.

The ionization pins and setup for registration on the scope is described in (10).

The scope we used to collect the results was GW Instek GDS-3352, Digital Storage Oscilloscope, 350 MHz 5 GS/s adjusted to DC. The other settings/conditions for the test firings are summarized in Table 2.4.

	Firing No 1 Cylindrical charge No 1	Firing No 2 Cylindrical charge No 8	Firing No 3 Cylindrical charge No 6	Firing No 4 Cylindrical charge No 7
Memory Length	25000	25000	25000	25000
Trigger Level	-2.64V	-2.64V	-2.64V	-2.64V
Source	CH1	CH1	CH1	CH1
Probe	1.000E+00	1.000E+00	1.000E+00	1.000E+00
Vertical Units	V	V	V	V
Vertical Scale	2.000E+00	2.000E+00	2.000E+00	2.000E+00
Vertical Position	6.480E+00	6.480E+00	6.480E+00	6.480E+00
Horizontal Units	S	S	S	S
Horizontal Scale	1.000E-05	1.000E-05	1.000E-05	1.000E-05
Horizontal Position	3.980E-05	3.980E-05	3.980E-05	3.980E-05
Horizontal Mode	Main	Main	Main	Main
Sampling Period	4.000E-09	4.000E-09	4.000E-09	4.000E-09
Firmware	V1.09	V1.09	V1.09	V1.09
Time	15.01.2014 12:55:32	15.01.2014 13:06:01	15.01.2014 13:17:14	15.01.2014 13:24:24
Mode	Detail	Detail	Detail	Detail
Waveform Data				

Table 2.4 The scope settings used to collect the results for the firings.

	Firing No 5 Cylindrical charge No 3	Firing No 6 Cylindrical charge No 5	Firing No 7 Conical charge 16/14	Firing No 8 Conical charge 19/14
Memory Length	25000	25000	25000	25000
Trigger Level	-2.64V	-2.64V	-2.64V	-2.64V
Source	CH1	CH1	CH1	CH1
Probe	1.000E+00	1.000E+00	1.000E+00	1.000E+00
Vertical Units	V	V	V	V
Vertical Scale	2.000E+00	2.000E+00	2.000E+00	2.000E+00
Vertical Position	6.480E+00	6.480E-00	4.000E+00	4.000E+00
Horizontal Units	S	S	S	S
Horizontal Scale	1.000E-05	1.000E-05	1.000E-05	1.000E-05
Horizontal Position	3.980E-05	3.98E-05	3.990E-05	3.990E-05
Horizontal Mode	Main	Main	Main	Main
Sampling Period	4.000E-09	4.000E-09	4.000E-09	4.000E-09
Firmware	V1.09	V1.09	V1.09	V1.09
Time	15.01.2014 13:29:21	20.01.2014 15:19:23	14.03.2014 10:30	14.03.2014 13:53:23
Mode	Detail	Detail	Detail	Detail
Waveform Data				

Table 2.5 The scope settings used to collect the results for the firings.

2.5 Pressure

Detonation pressure has been determined by use of the Plate Dent test (12-13). Bolt steel plates of ST-52 quality with diameter 160 mm were used as witness plate. For the charges with diameter 35-36 mm the plates had a height of 60 mm. Figure 2.12 shows how the Dent depth was measured with a micrometer screw, a steel ring and a steel ball.

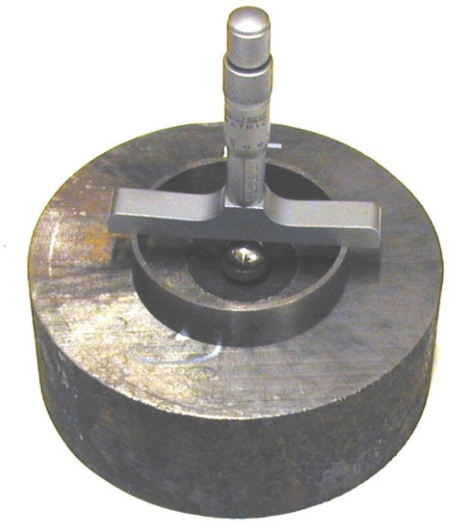

Figure 2.12 Picture of the tool used to measure the Dent depth.

2.6 Initiation

All firings were performed with a booster of HWC and a detonator No 8. Appendix A gives the certificate of the used HWC explosive. 35 g boosters were pressed in a tool with diameter 31.5 mm with 10 tons pressure and a dwell time of 60 seconds. For charges with diameter 36±1 mm 80 g donor pellets for Intermediate Scale Gap test were used as boosters. These pellets had a density of 1.60 g/cm^3 and a diameter of 40 mm. For the firings performed at Bradalsmyra the boosters were pressed at Nammo.

2.7 Theoretical calculations

All theoretical calculations were performed with Cheetah 2.0 (14).

3 Results

3.1 Critical diameter

3.1.1 Conical charge No 1

The first charge we tested had a length of only 13 cm. In Figure 3.1 pictures of the charge before it was placed on the witness plate (left), setup for test firing (middle) and of the recovered witness plate after firing (right) are shown.

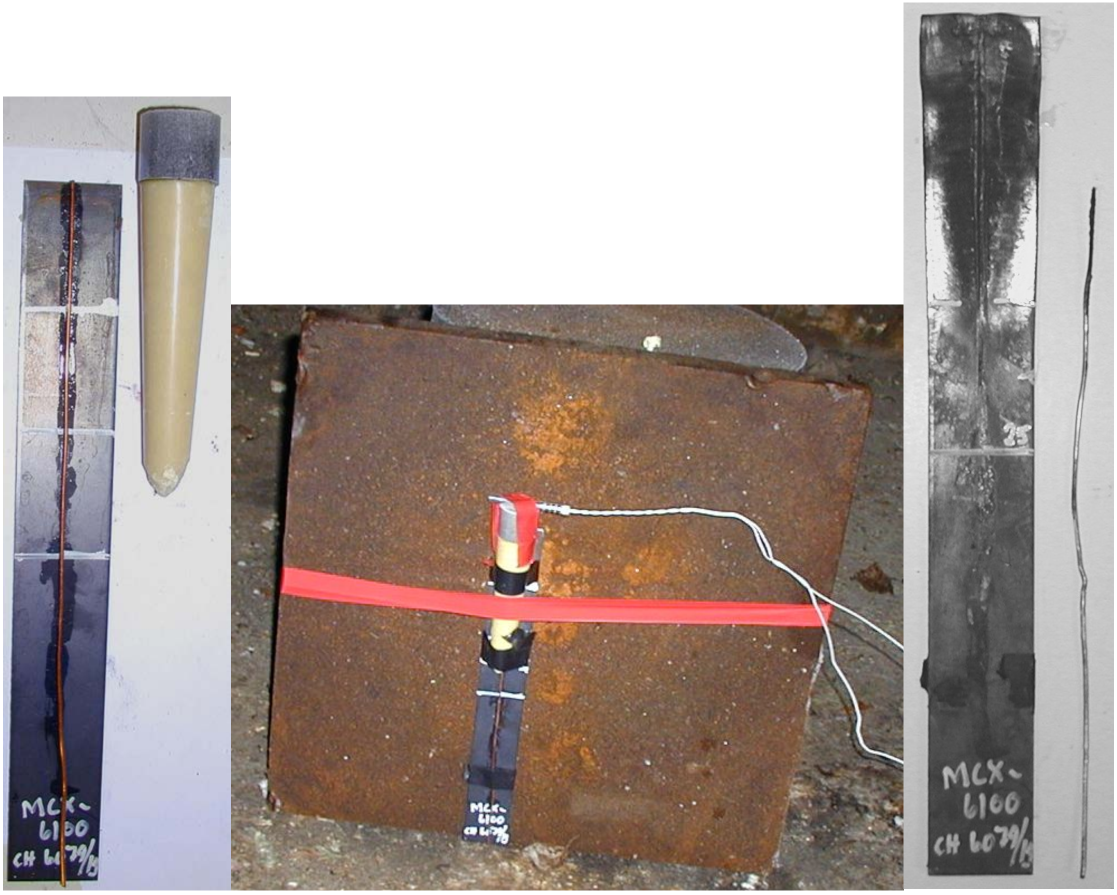

Figure 3.1 Pictures of the test item before it was assembled to the witness plate (left), test setup (middle) and witness plate after firing (right).

The witness plate gives a critical diameter of 19.2 mm for this test item.

3.1.2 Conical charge No 2

The second charge to be tested was cast No 3/14. As Figure 3.2 shows this charge was longer than the first one. The Figure shows how the charge was placed on the witness plate, test setup and the witness plate after firing. From the witness plate we can see that the detonation had propagated 12-13 cm down the charge. Exact measurement gives a critical diameter of 16.8 mm, slightly smaller than for the first charge we tested.

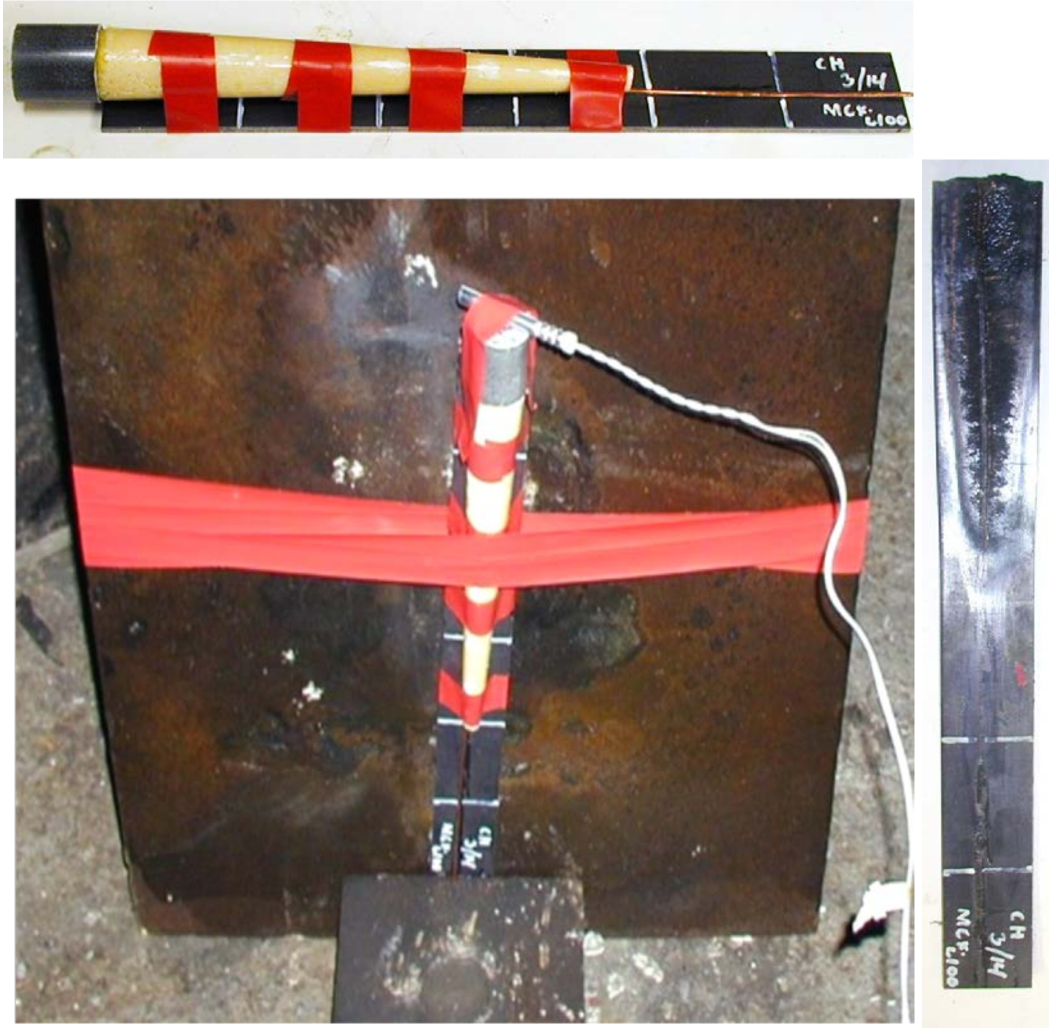

Figure 3.2 The test item after being assembled (top), setup for firing (central) and the witness plate after firing (right).

3.1.3 Conical charge No 3

The third charge we tested was from the same cast as the second one 3/14 but item 14.2. Figure 3.3 shows the test setup and the witness plate after firing. The upper diameter of this conical charge was only 26.3 mm but large enough to obtain a stable detonation before the critical diameter was reached. From the witness plate it can be observed that the detonation stopped at a critical diameter of 19.2 mm.

Figure 3.3 Pictures of test item, setup and witness plate for conical charge No 3 after firing (right).

3.1.4 Conical charge No 4

The last two conical charges we tested were each instrumented with 4 ionization pins to measure detonation velocity. The assembled test item, setup for firing and the witness plate after firing are all shown in Figure 3.4 for cast 16/14 of CH 6079/13. From the witness plate we can see that the critical diameter is 19.5 mm. The ionization pins were positioned at a critical diameter of 27.2 mm, 24.2 mm, 21.2 mm and 18.2 mm. For this firing we got registration from one pin only, so we did not get any information about critical diameter from the ionization pins.

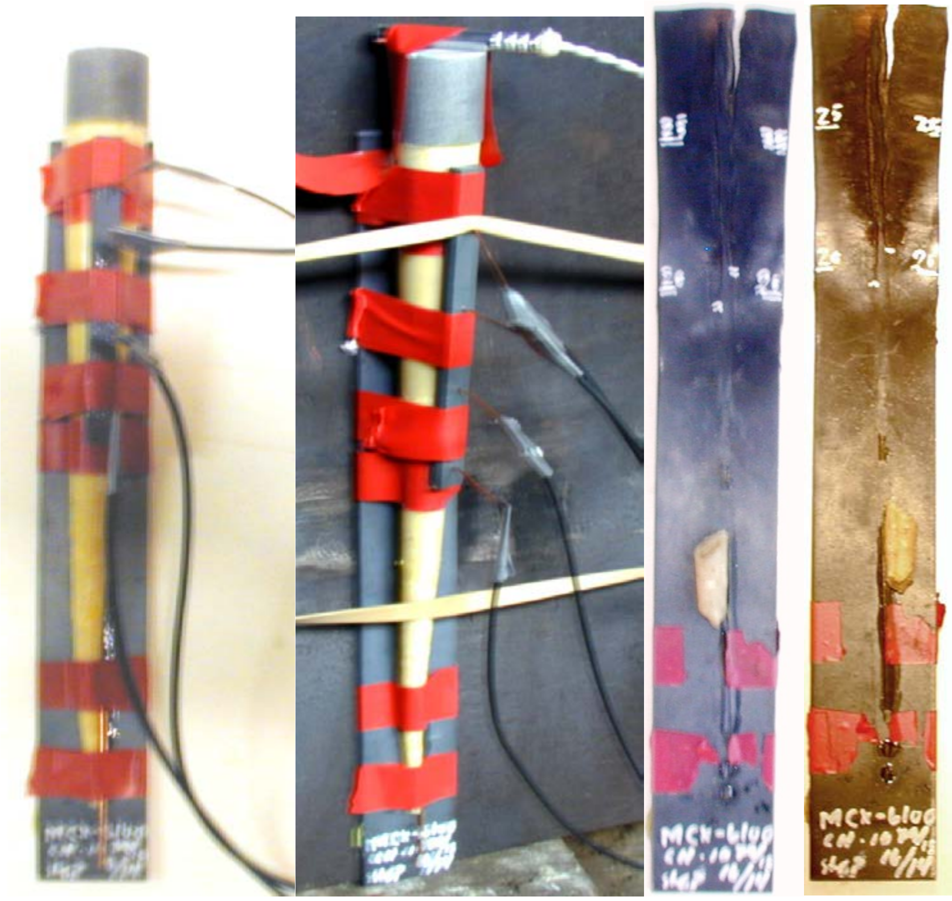

Figure 3.4 Test item after it was assembled (left), the test setup (middle) and to the right the witness plate after firing.

3.1.5 Conical charge No 5

The last charge we tested was cast No 19/14. Figure 3.5 shows pictures, from left to right, of the test item after being placed on the witness plate, after 4 ionization pins were added, setup for the firing and the witness plate after firing. For this firing we got registrations for three ionization pins at a critical diameter of 27 mm, 24 mm and at 21 mm. For the last ionization pin at a critical diameter of 18 mm no registration was obtained. As will be seen in 3.2.7 the velocity between pin No 2 and No 3 is low, indicating that the detonation is close to termination at a diameter of 21 mm. From the witness plate we read a critical diameter of 20.8 mm for this test item.

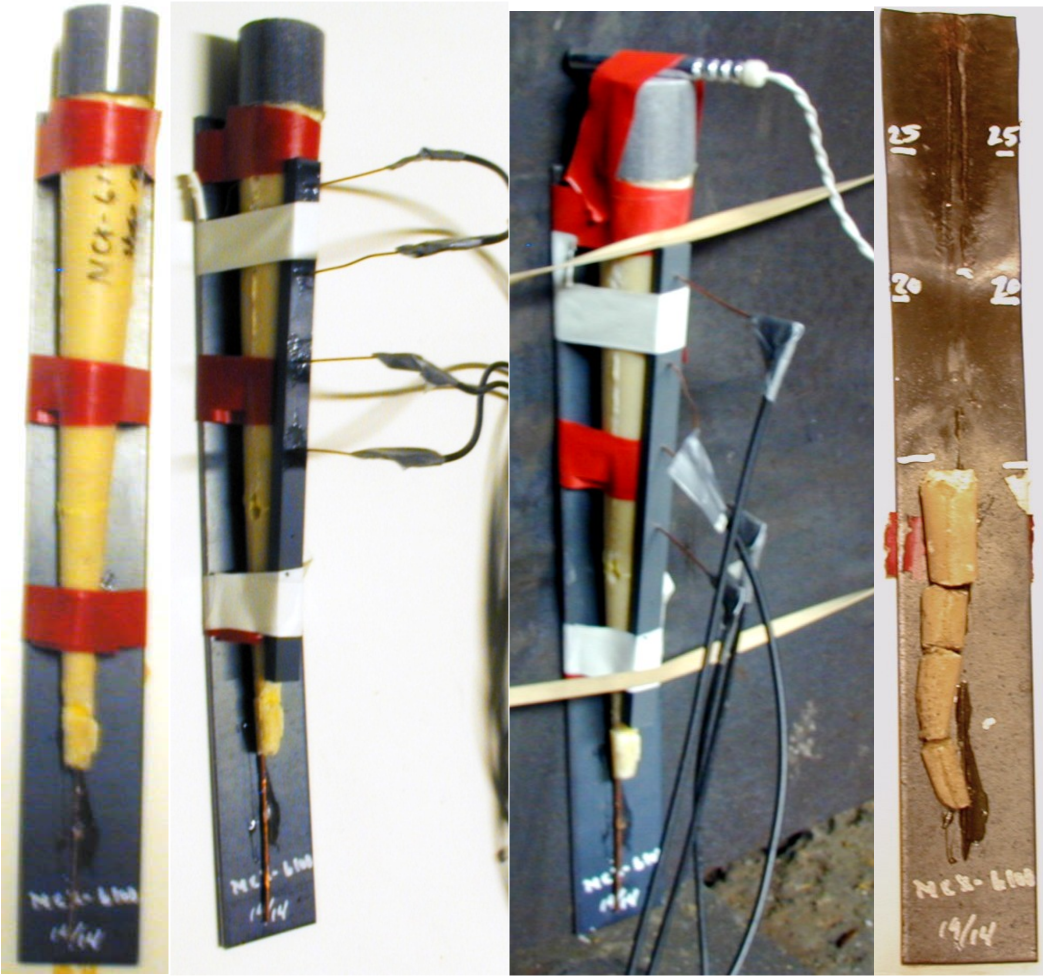

Figure 3.5 The figure shows the assembled test item without and with ionization pins, setup for firing and the witness plate with recovered unreacted explosive.

3.1.6 Summary of critical diameter results

Table 3.1 summarizes the results for the five test items we have tested containing MCX-6100. As the table shows the results are relatively reproducible with a critical diameter of 19.1±1.4 mm. The out-layer is test item No 2 for which we obtained 16.8 mm. Figure 3.6 shows a picture of the five witness plates. For two of the firings we recovered some unreacted explosive.

Test item No	**CH 6079/13 Cast**	**Density (g/cm^3)**	**Critical Diameter (mm)**
1		1.685	19.2
2	3/14 No 1	1.687	16.8
3	3/14 No 2	1.746	19.2
4	16/14	1.676	19.5
5	19/14	1.685	20.8
Average 1-5			**19.1±1.4**
Average 1, 3-5			**19.7±0.8**

Table 3.1 The table summarizing critical diameter results for tested explosive charges

The obtained critical diameter for MCX-6100 CH 6079/13 of 20 mm is in the same range as given in the literature for IMX-104 compositions (8).

Figure 3.6 Witness plates for the five performed tests for determination of the critical diameter of MCX-6100 CH 6079/13.

3.2 Detonation velocity

3.2.1 Firing No 1

The first firing was with charge No 1 having a density of 1.74 g/cm^3. The charge was instrumented with 4 ionization pins as shown in Figure 3.7. The distance between pin No 1 and No 2 was 90 mm, distance between pin No 2 and pin No 3 was 60 mm, and finally between pin No 3 and pin No 4 the distance was 60 mm. The test item was placed directly on a 60 mm thick Dent plate before firing. Registration was obtained for all 4 ionization pins. Figure 3.8 shows a plot of arrival times and distances between all ionization pins. Table 3.2 gives in addition calculated detonation velocities.

Figure 3.7 Test setup for determination of detonation velocity and pressure for charge No 1 containing MCX-6100 CH 6079/13.

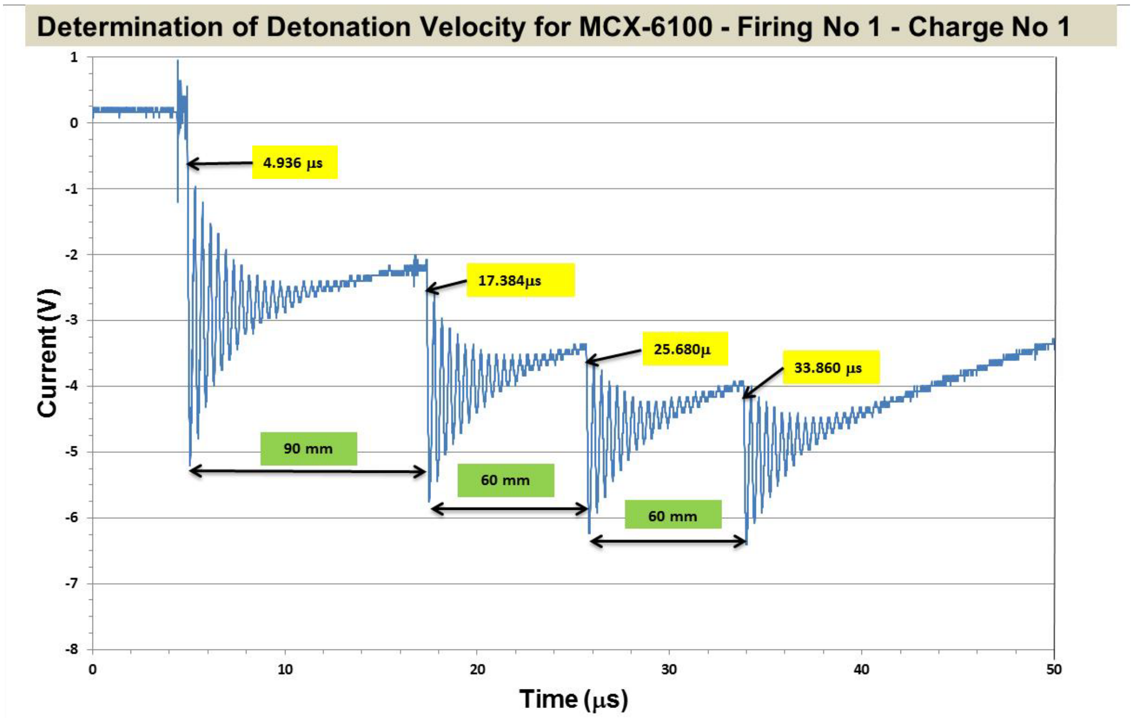

Figure 3.8 The figure shows the arrival times of the detonation front from each ionization pin in addition to the distances between the pins for firing No 1.

Obtained detonation velocities, between pin No 1 and pin No 2 was7230 m/s, between pin No 2 and pin No 3 it was 7232 m/s and finally between pin No 3 and pin No 4 it was 7335 m/s, all as expected since the density most probably is highest in the bottom of the charge. The overall detonation velocity between ionization pin No 1 and ionization pin No 4 is 7260 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-6100			
1	4.936			
2	17.384	12.448	90	7230
3	25.68	8.296	60	7232
4	33.86	8.180	60	7335
1-4		28.924	210	**7260**

Table 3.2 Summary of the results from the measurements of the detonation velocity for MCX-6100 CH 6079/13 charge No 1.

3.2.2 Firing No 2

Charge 8 was instrumented with 4 ionization pins. The distance between pin No 1 and pin No 2 was 100 mm, while between pin No 2 and pin No 3 and between pin No 3 and pin No 4 the distance was 50 mm. Figure 3.9 shows pictures of the charge before firing.

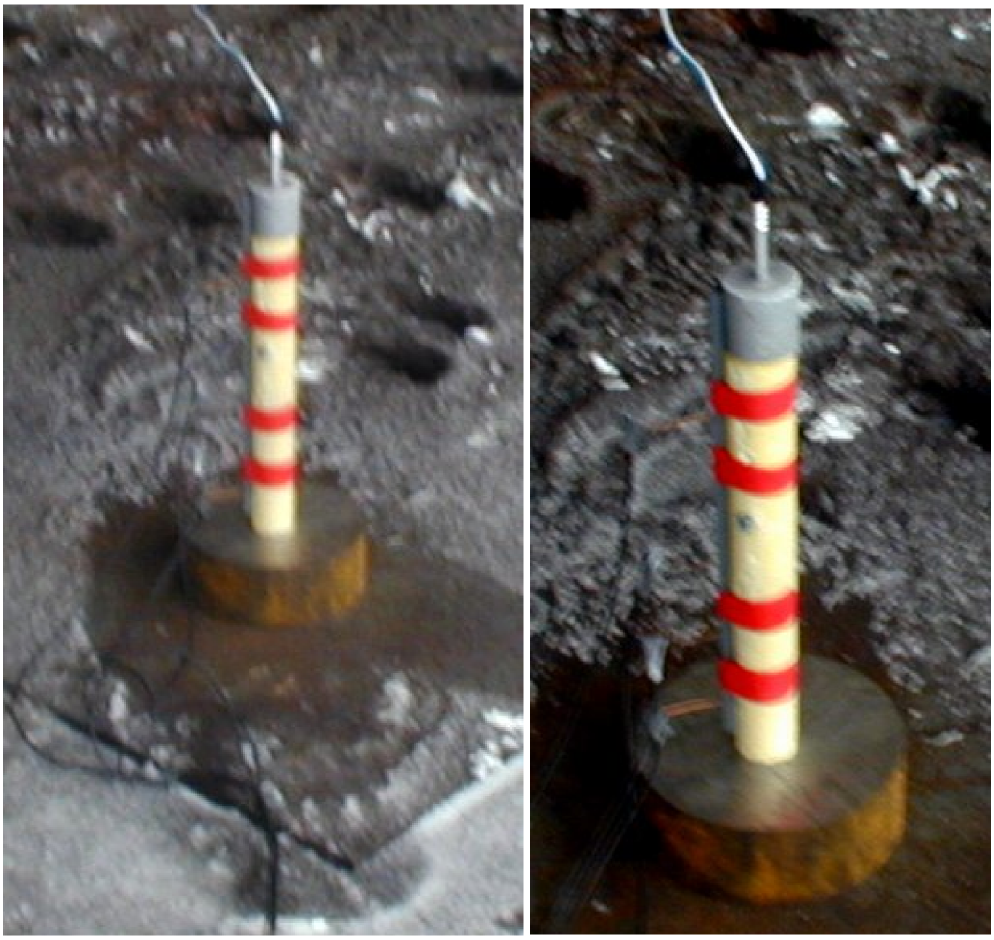

Figure 3.9 Charge No 8 before testing.

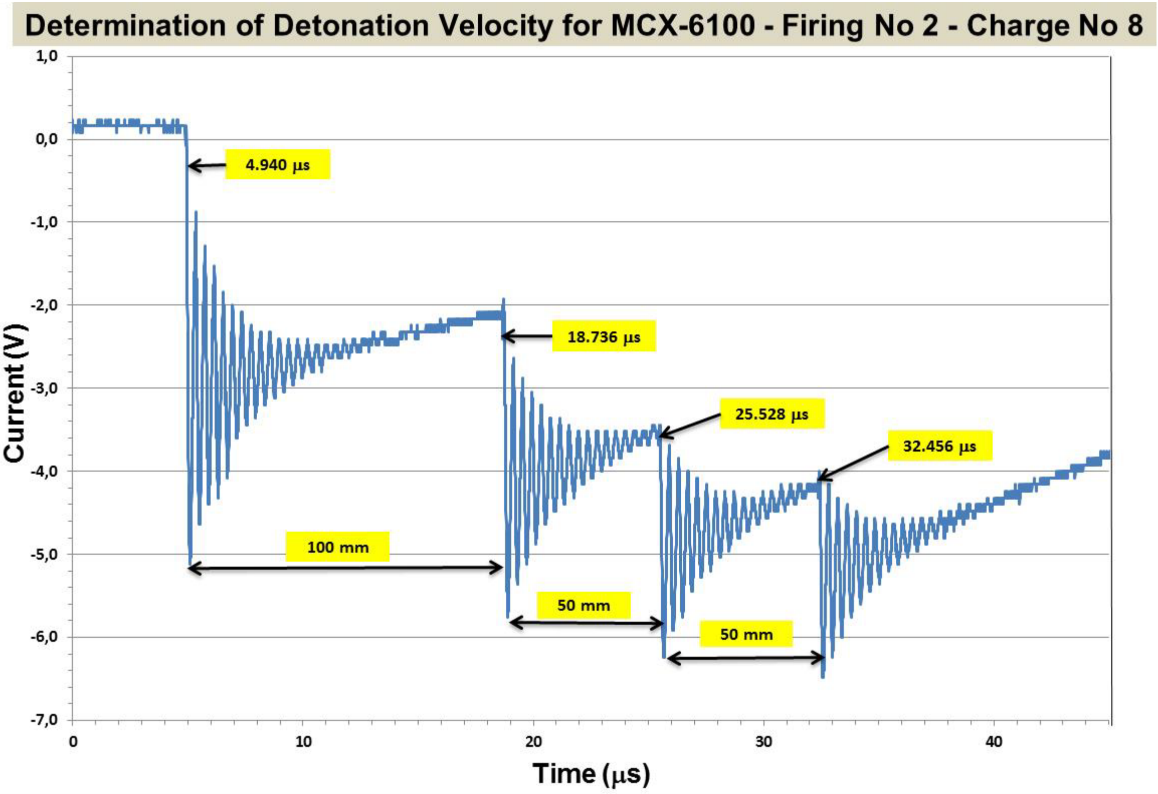

Figure 3.10 Arrival times of the detonation front for each ionization pin in addition to the distance between the pins.

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-6100			
1	4.940			
2	18.736	13.796	100	7248
3	25.528	6.792	50	7362
4	32.456	6.928	50	7217
1-4		27.516	200	**7268**

Table 3.3 Summary of the results from the measurements of the detonation velocity for MCX 6100 CH 6079/13 charge No 8.

Figure 3.10 gives arrival times and distances between ionization pins. Table 3.3 gives in addition calculated detonation velocities. The overall velocity between pin No 1 and pin No 4 is 7268 m/s or 6 m/s faster than for firing No 1. For charge No 8 the detonation velocity for the first half of the charge is 40 m/s lower than for the bottom.

3.2.3 Firing No 3

The third firing was with charge No 6 having a density of 1.70 g/cm^3. Figure 3.11 shows pictures of the test setup. The test item was equipped with 4 ionization pins. The distance between pin No 1 and pin No 2 was 100 mm, between pin No 2 and pin No 3 50 mm and between pin No 3 and pin No 4 50 mm. Unfortunately, for this firing we did not get registration from the last ionization pin, Figure 3.12.

Figure 3.11 Charge No 6 before testing.

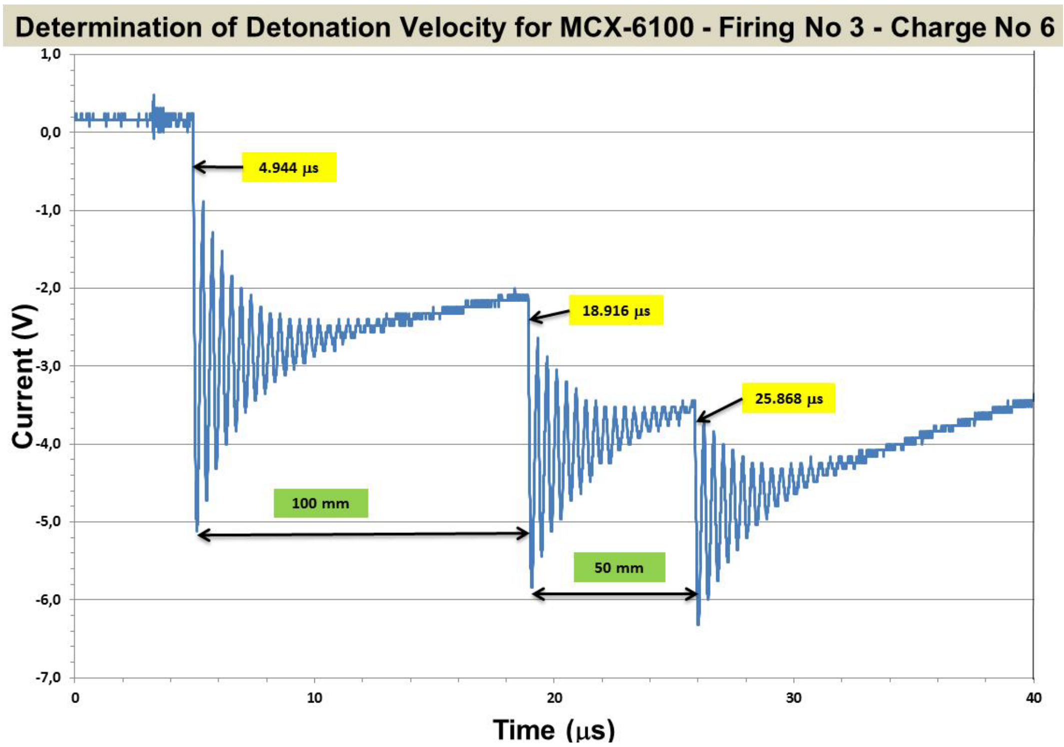

Figure 3.12 Arrival times of the detonation front for each ionization pin in addition to the distance between the pins. Registration for pin No 4 failed.

Figure 3.12 gives arrival times of the detonation front and the distances between each pin. Table 3.4 gives in addition calculated detonation velocities. The overall detonation velocity is calculated to 7169 m/s or approximately 100 m/s lower than for the two first firings.

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 3 containing MCX-6100			
1	4.944			
2	18.916	13.972	100	7157
3	25.868	6.952	50	7192
4	No registration			
1-3		20.924	150	7169

Table 3.4 Summary of the results from the measurements of the detonation velocity for MCX 6100 CH 6079/13 charge No 6.

3.2.4 Firing No 4

Firing No 4 with CH 6079/13 was with charge No 7 having an overall density of 1.69 g/cm^3. Figure 3.13 shows the test setup. The test item was equipped with 4 ionization pins. The distances between pin No 1 and pin No 2, pin No 2 and pin No 3 and finally between pin No 3 and pin No 4 were all 60 mm.

Figure 3.13 Setup for firing No 4 with charge No 7 of MCX-6100 CH 6079/13.

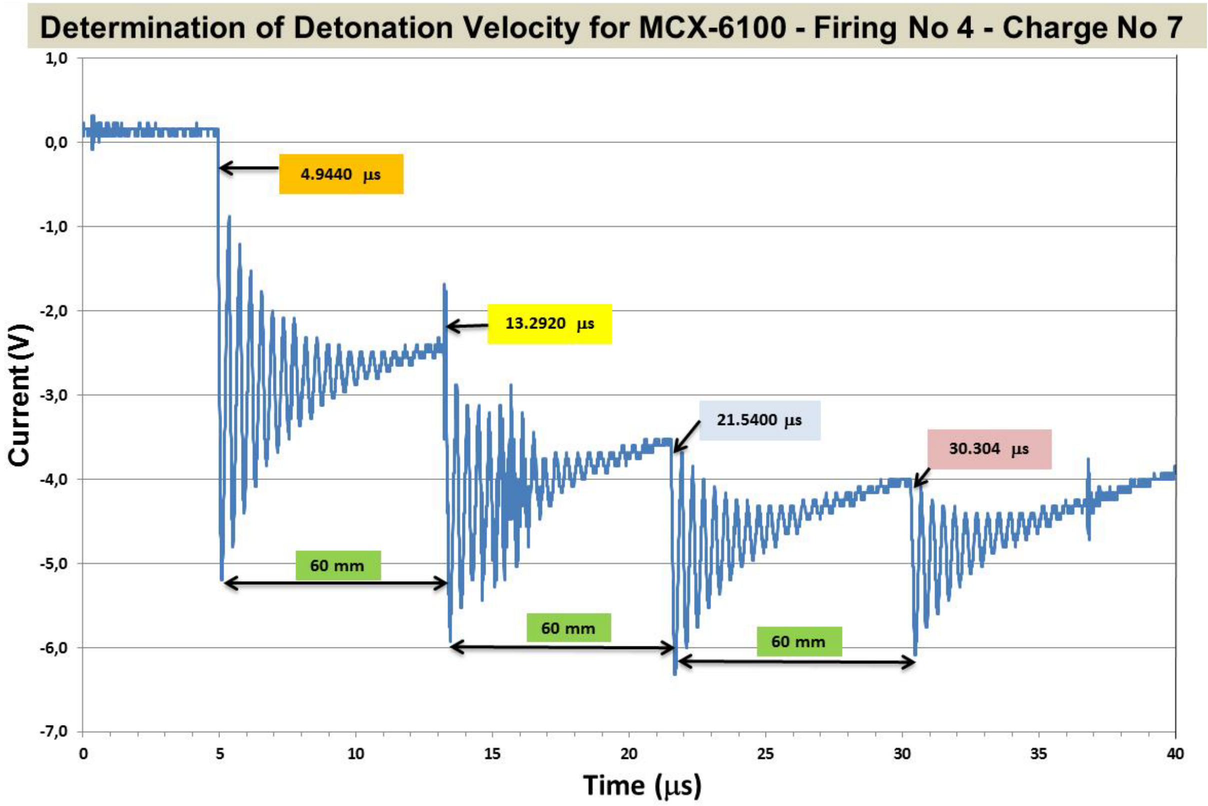

Figure 3.14 Arrival times of the detonation front from each ionization pin in addition to the distances between the pins.

Figure 3.14 shows the arrival times and distances between ionization pins. Table 3.5 gives in addition the calculated velocities. The overall detonation velocity of 7098 m/s is the lowest we have measured for the 4 first firings. The three first registrations give detonation velocities similar to the other firings. The obtained velocity between pin No 3 and pin No 4 of 6846 m/s is however significantly lower than the two first velocities. Normally the opposite is observed for this type of compositions having the possibility for sedimentation. From the X-ray picture in Figure 2.2 it is difficult to see any defects that can explain the obtained results.

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 4 containing MCX-6100			
1	4.9440			
2	13.2920	8.348	60	7187
3	21.5400	8.248	60	7274
4	30.3040	8.764	60	6846
1-4		25.36	180	**7098**

Table 3.5 Summary of the results from the measurements of the detonation velocity for MCX 6100 CH 6079/13 charge No 7.

3.2.5 Firing No 5

Firing No 5 was with charge No 3 containing 4 ionization pins with 50 mm between pin No 1and pin No 2 and 100 mm between pin No 2 and pin No 3 and finally 50 mm between pin No 3 and pin No 4. Unfortunately for this firing we did not obtain any signals at the scope. After the firing the contact for the pin connection to the pin switch box was broken-disconnected. However the detonation pressure was obtained and is given in 3.3.

Figure 3.15 Charge No 3 before firing.

3.2.6 Firing No 6

Firing No 6 was with charge No 5. This charge had been divided into three parts for determination of density. The test item was glued together in the order 2-1-3 after being divided. Part 1was the bottom and part 3 the top of the original charge. Figure 3.16 shows pictures of the original charge, the test item after being equipped with 6 ionization pins and the setup used for firing. The upper part of the charge with a density of 1.656 g/cm^3 was equipped with two ionization pins, pin No 1 and pin No 2. The distance between the pins was 60 mm. The centre part was taken from the bottom of the original charge having a density of 1.772 g/cm^3. Also this part was fitted with two ionization pins, pin No 3 and pin No 4. The distance between the pins was 60 mm. The distance between pin No 2 and pin No 3 was 30 mm. The bottom part of the new test item was taken from the central part of the original charge with a density of 1.701 g/cm^3. Two ionization pins, No 5 and pin No 6 were connected. The distance between these pins was 60 mm. The distance between pin No 4 and pin No 5 was 30 mm.

We obtained registrations from 5 of the 6 ionization pins. Pin No 6 gave no registration, most probably due to some bad contact in the coaxial cable. Figure 3.17 gives the arrival times and the distances between the ionization pins. Table 3.6 gives in addition calculated detonation velocities.

Figure 3.16 The figure shows at left the original charge, in the middle the test item after being assembled with ionization pins and to the right the test setup for the firing.

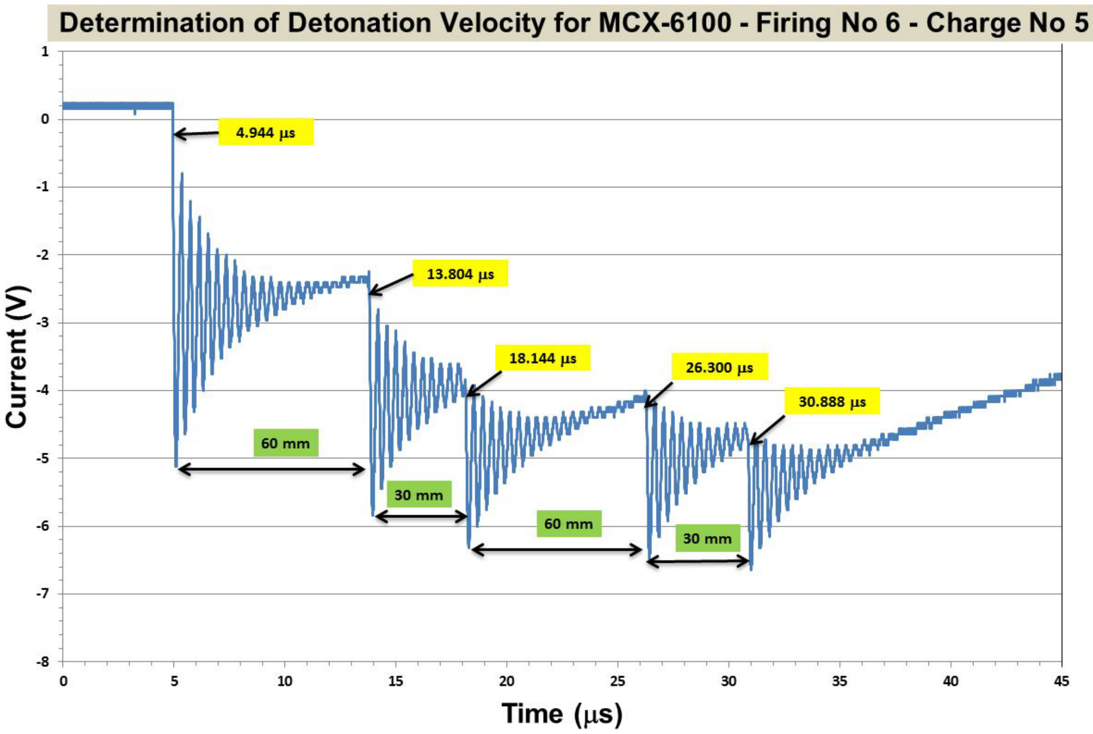

Figure 3.17 Arrival times and distances for each ionization pin.

The overall detonation velocity of 6938 m/s is as expected due to its low density the lowest of the five charges having diameter 36±1 mm. For to the individual measurements the results look reasonable with the highest detonation velocity for the part of the charge with the highest density.

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 6 containing MCX-6100			
1	4.944			
2	13.804	8.860	60	6772
3	18.144	4.340	30	6912
4	26.300	8.156	60	7357
5	30.888	4.588	30	6539
1-5		25.944	180	**6938**

Table 3.6 Summary of the results from the measurements of the detonation velocity for MCX 6100 CH 6079/13 charge No 5.

3.2.7 Conical charges

3.2.7.1 Cast 16/14

Two of the conical charges tested to determinate critical diameter were equipped with ionization pins to simultaneously measure detonation velocity and critical diameter. The first conical charge to be tested was cast No 16/14 with the properties given in 2.3.4.

The positions of the ionization pins are shown in Figure 3.18 together with a picture of the test setup. Unfortunately only one of the ionization pins gave registration. With registration for only one ionization pin we do not have information to determinate detonation transition. However the critical diameter was determined from the witness plate shown in Figure 3.4.

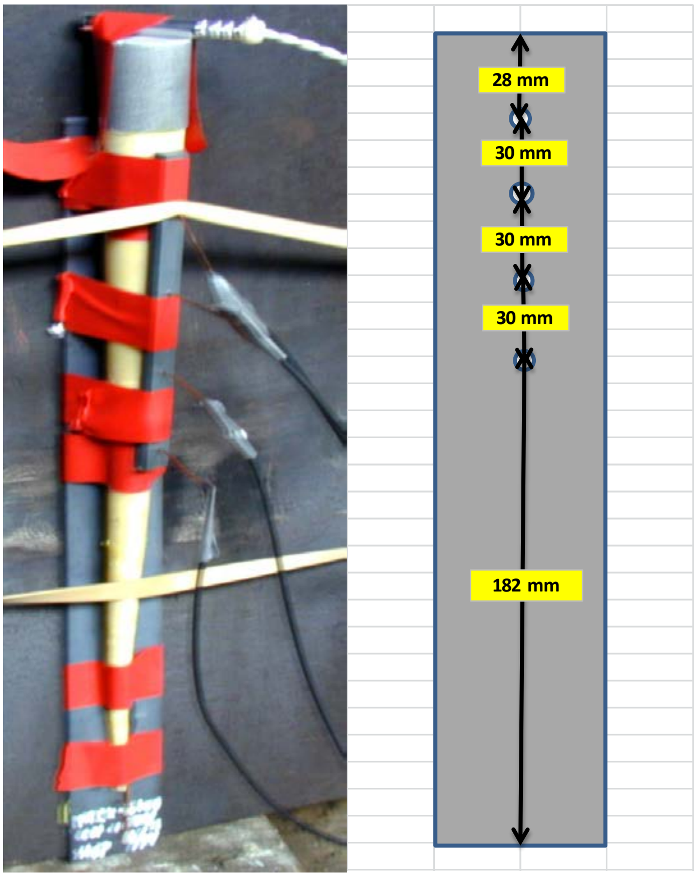

Figure 3.18 Test setup and the positions of the ionization pins.

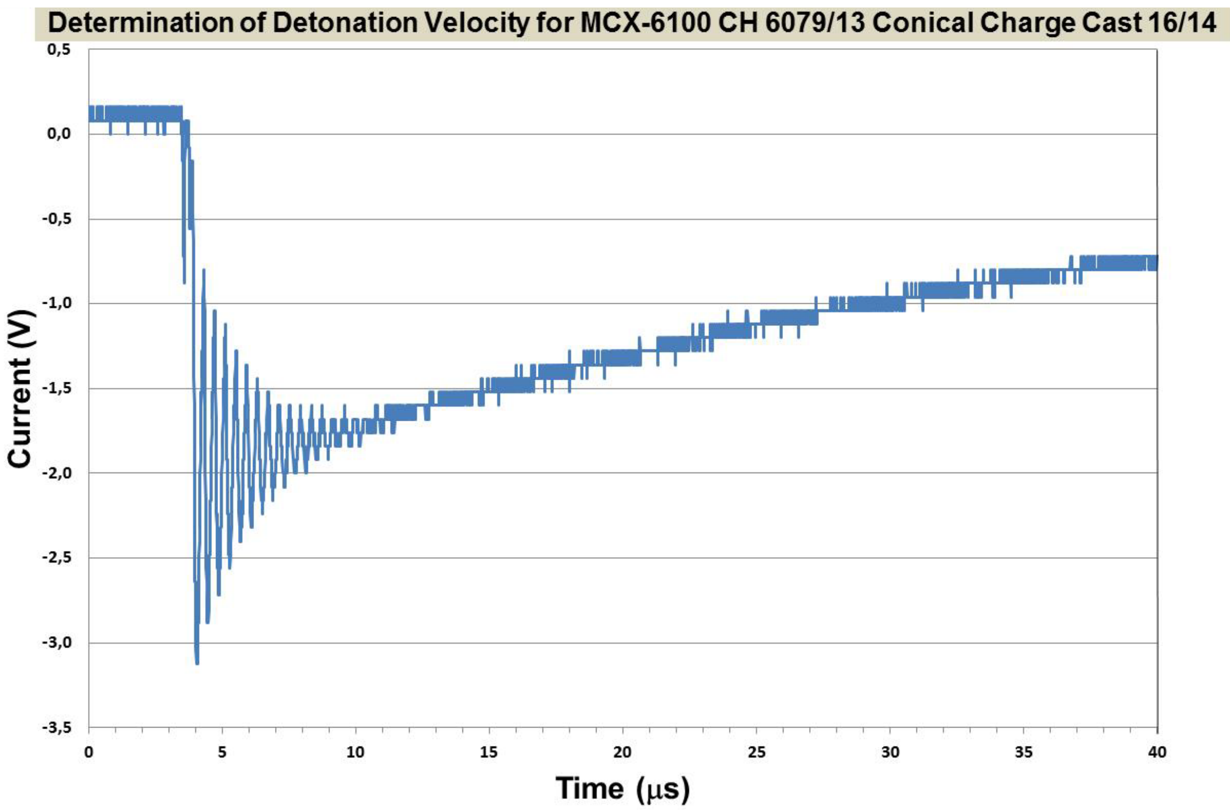

Figure 3.19 Registration obtained at the scope.

3.2.7.2 Cast 19/14

The next conical charge to be tested was cast 19/14 with properties given in 2.3.5. This test item as cast 16/14 was equipped with 4 ionization pins. The positions of these pins are shown in Figure 3.20. Figure 3.20 gives in addition the setup used for the firing and the registration of the firing on the scope. The distance between each pin was 30 mm. We obtained registration for three out of four ionization pins. From the initial tests of critical diameter we had found a critical diameter for MCX-6100 CH 6079/13 of approximately 19-20 mm. The forth ionization pin was placed at a charge diameter of 18 mm. Therefor it was expected that it could fail. Figure 3.21 gives the arrival times of the detonation front and the distances between pins with registration.

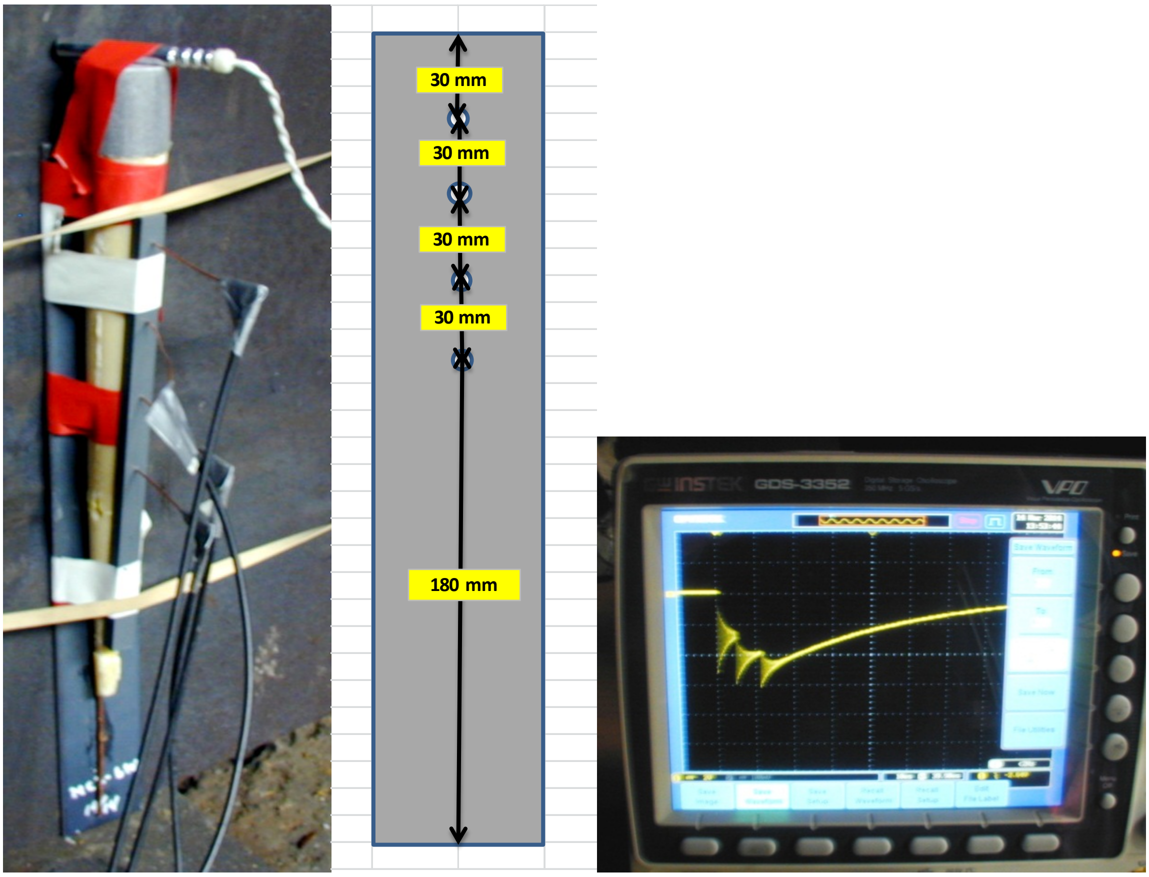

Figure 3.20 Test setup and position of ionization pins for conical charge cast 19/14 with MCX-6100 CH 6079/13. Picture to the right shows scope registration after firing.

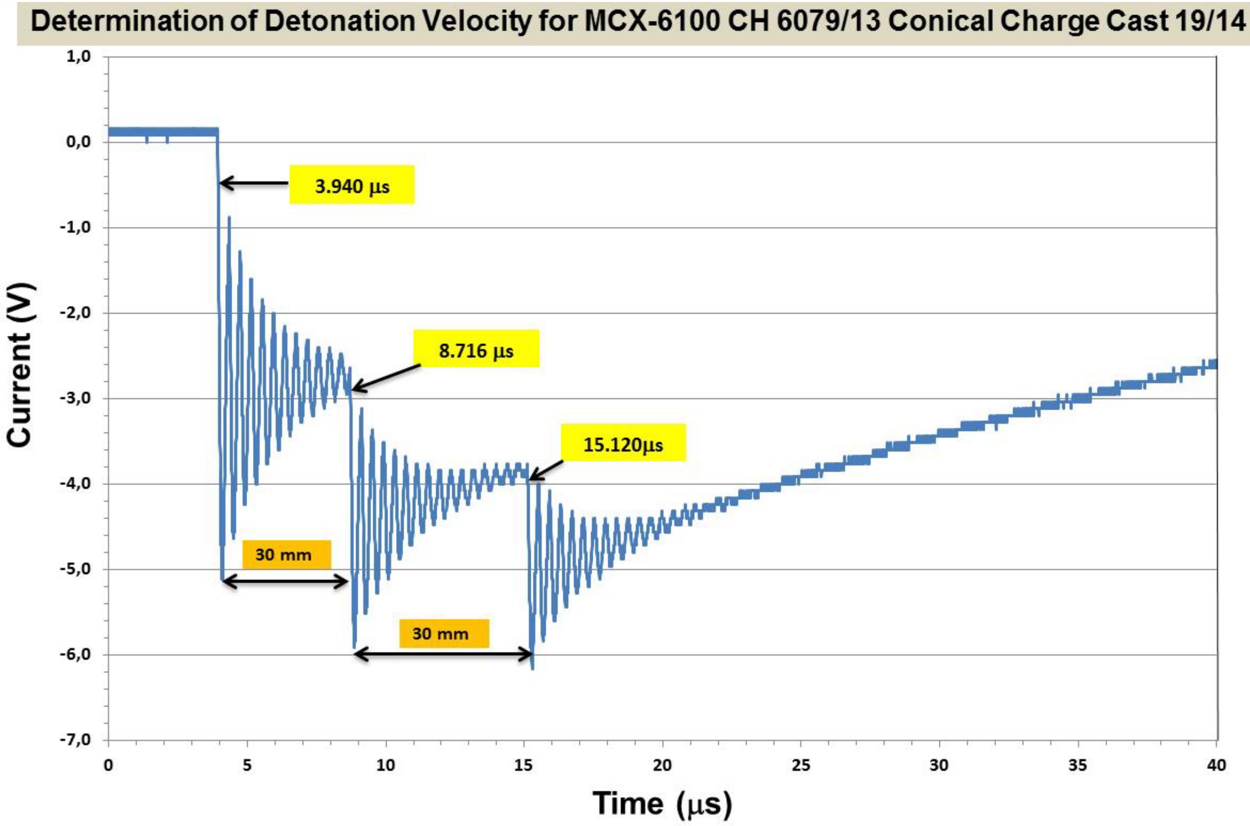

Figure 3.21 Arrival times of the detonation front from each pin and the distances between pins.

Table 3.7 gives the calculated detonation velocities. The first velocity of 6281 m/s between pin No 1at CD (charge diameter) 27 mm and pin No 2 at CD 24 mm is significantly lower than for the 36 mm charges tested earlier. The last velocity between CD 24 mm (pin No 2) and CD 21 mm (pin No 3) is only 4685 m/s indicating that the detonation is close to termination. Of the same reason is the velocity between pin No 1 and pin No 3 of 5367 m/s very low.

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 8 containing MCX-6100			
1	3.940			
2	8.716	4.776	30	6281
3	15.12	6.404	30	4685
4	No registration			
1-3				***5367***

Table 3.7 Summary of the results from the measurements of the detonation velocity for MCX-6100 CH 6079/13 conical test item cast 19/14.

3.2.8 Summary of detonation velocity determinations

Table 3.8 summarizes all the detonation velocity determinations performed in this report for MCX-6100 CH 6079/13. The obtained results show moderate variations both inside the same charge and between charges.

Firing No	Cast No	Charge diameter (mm)	Charge density (g/cm3)	Between pin No	Measuring distance (mm)	Detonation velocity (m/s)
1	1	35-38	1.74	1-2	90	7230
				2-3	60	7232
				3-4	60	7335
				1-4	210	**7260**
2	8	34.8-38	1.71	1-2	100	7248
				2-3	50	7362
				3-4	50	7217
				1-4	200	**7268**
3	6	35.1-38	1.70	1-2	100	7157
				2-3	50	7192
				3-4	50	
				1-3	150	**7169**
4	7	35-38	1.69	1-2	60	7187
				2-3	60	7274
				3-4	60	6846
				1-4	180	**7098**
6	5	36.2-37.85	1.656	1-2	60	6772
				2-3	30	6912
		34.7-35.2	1.772	3-4	60	7357
				4-5	30	6539
		35.2-36.03	1.701	5-6	60	
				1-5	180	**6938**
8	19/14 Conical charge	27-18	1.685	1-2	30	6281
				2-3	30	4685
				3-4	30	
				1-3	90	**5367**

Table 3.8 Summary of the measured detonation velocities for tested charges of MCX-6100 CH 6079/13.

Table 3.9 gives detonation velocities for all charges. The results show correlation between density and velocity. High density gives high velocity, Figure 3.22. Figure 3.22 also includes a test result from NEXTER Munitions of MCX-6100 given in reference 15. MCX-6100 is based on the same ingredients as IMX-104. The difference between IMX-104 and MCX-6100 is only minor differences in the content of RDX and DNAN. In the literature nominal detonation velocity for IMX-104 is reported to be 7.4 km/s. In addition IMX-104 the detonation velocity increases slightly as the diameter increases (16). Figure 3.23 gives a plot of the results in reference (16). Reference (16) says nothing about the density of the tested samples, only the diameter. For comparison of our experimental results with theoretical values see 3.4.

Firing No	Cast No	Charge diameter (mm)	Charge density (g/cm3)	Between pin No	Measuring distance (mm)	Detonation velocity (m/s)
1	1	35-38	1.74	1-4	210	**7260**
2	8	34.8-38	1.71	1-4	200	**7268**
3	6	35.1-38	1.70	1-3	150	**7169**
4	7	35-38	1.69	1-4	180	**7098**
6	5	36.2-37.85	1.656	1-2	60	6772
		34.7-35.2	1.772	3-4	60	7357
		35.2-36.03	1.701	1-5	180	**6938**
7	19/14 Conical charge	27-18	1.685	1-2	30	6281
				2-3	30	4685
				1-3	90	**5367**

Table 3.9 Experimentally determined detonation velocities for MCX-6100 charges.

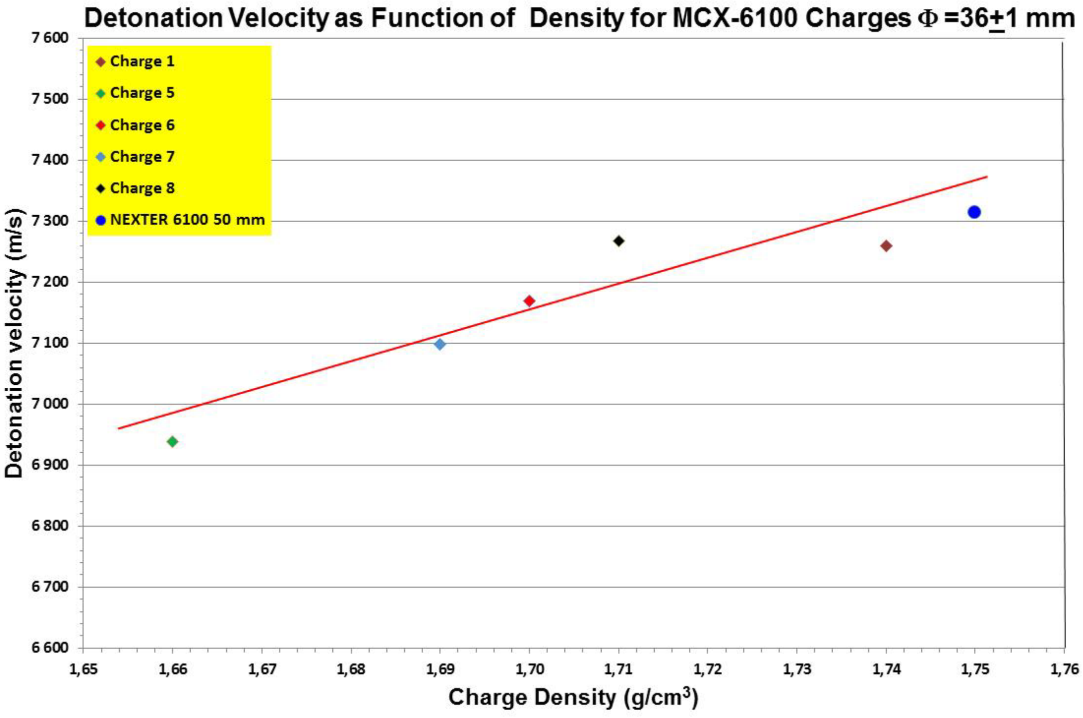

Figure 3.22 Plot of detonation velocity as function of charge density for MCX-6100 CH 6079/13.

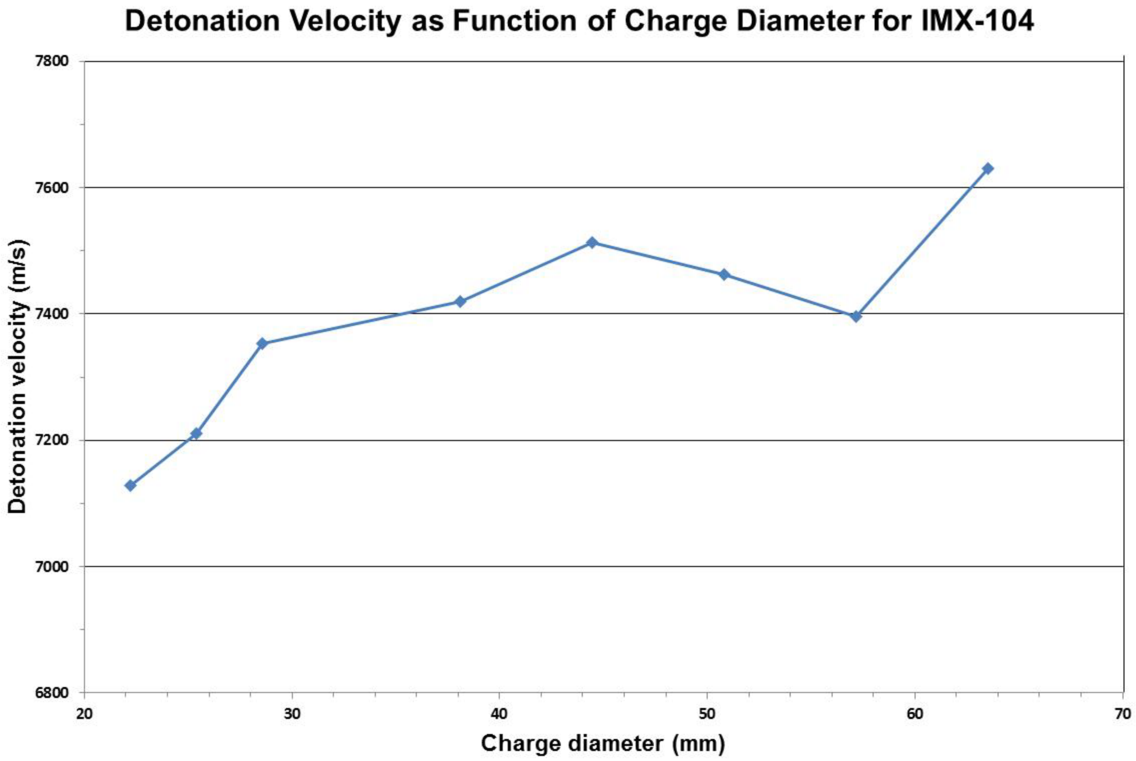

Figure 3.23 Plot of detonation velocity as function of charge diameter for IMX-104 from (16).

3.3 Detonation Pressure

Detonation pressure was determined by use of the Plate Dent Test. The witness plates were cylindrical with a diameter of 160 mm and a thickness of 60 mm of ST-52 quality steel. Appendix A gives the certificate for the used steel.

3.3.1 Firing No 1

The first firing was with charge No 1 having a diameter of 35.0 mm. Test setup is given in Figure 3.7 and a picture of the Dent plate after firing is given in Figure 3.24.

Figure 3.24 Picture of the Dent plate after firing of MCX-6100 CH 6079/13 charge No 1.

The dent depth was measured with the tool shown in Figure 2.12. The Dent depth was measured to be 4.72 mm. Utilizing the calibration in (12) this Dent depth corresponds to a detonation pressure of 194 kbar.

3.3.2 Firing No 2

The second firing was with charge No 8 having a diameter of 34.8 mm. Test setup is given in Figure 3.9 and a picture of the Dent plate after the firing is given in Figure 3.25.

Figure 3.25 Picture of the Dent plate after firing of MCX-6100 CH 6079/13 charge No 8.

Dent depth was measured to 4.61 mm, which corresponds to a detonation pressure of 191 kbar.

3.3.3 Firing No 3

The third firing was with charge No 6 having a diameter of 35.1 mm. Test setup is given in Figure 3.11 and a picture of the Dent plate after firing is given in Figure 3.26.

Figure 3.26 Picture of the Dent plate after firing of MCX-6100 CH 6079/13 charge No 3.

The Dent depth was measured to 4.77 mm corresponding to a detonation pressure of 196 kbar.

3.3.4 Firing No 4

The fourth firing was with charge No 7 having a diameter of 35.0 mm. Test setup is given in Figure 3.13 and a picture of the Dent plate after firing is given in Figure 3.27.

Figure 3.27 Picture of the Dent plate after firing of MCX-6100 CH 6079/13 charge No 7.

Dent depth was measured to be 4.34 mm corresponding to a detonation pressure of 179 kbar.

3.3.5 Firing No 5

The fifth firing was with charge No 3 having a diameter of 35.1 mm. Test setup is given in Figure 3.15 and a picture of the Dent plate after firing is given in Figure 3.28.

Figure 3.28 Picture of the Dent plate after firing of MCX-6100 CH 6079/13 charge No 3.

Dent depth was measured to 4.75 mm corresponding to a detonation pressure of 195 kbar.

3.3.6 Firing No 6

The last firing was with charge No 5 having a diameter of 35.2 mm. Test setup is given in Figure 3.16 and a picture of the Dent plate after firing is given in Figure 3.29.

Figure 3.29 Picture of the Dent plate after firing of MCX-6100 CH 6079/13 charge No 5.

Dent depth was measured to be 4.46 mm corresponding to a detonation pressure of 182 kbar.

3.3.7 Summary – Dent results

Table 3.10 summarizes the obtained detonation pressures for the 6 firings performed with MCX-6100 CH 6079/13 composition. The variations in the results are small taken into consideration the variation in diameter and density of the test items. However, the average detonation pressure of 190 kbar is lower than one should expect for this composition.

Firing No	Charge Diameter (mm)	Charge density (g/cm^3)	Dent (mm)	Detonation Pressure (kbar)
1	35.0	1.74	4.72	**194**
2	34.8	1.71	4.61	**191**
3	35.1	1.70	4.77	**196**
4	35.0	1.69	4.34	**179**
5	35.1	1.74	4.75	**195**
6	35.2	1.70	4.46	**182**
Average				**190$\pm$7**

Table 3.10 Experimentally measured detonation pressures for MCX 6100 CH 6079/13 charges.

3.4 Theoretical calculations

Theoretical calculations with Cheetah 2.0 (14) have been performed for the nominal content of MCX-6100 with 32 wt. % DNAN, 15 wt. % RDX and 53 wt. % NTO for different densities.

Calculations have been performed with both the BKWC and the BKWS product library. Appendix C gives summary print out for all calculations, while the obtained detonation pressures and velocities are summarized in Table 3.11.

Density (g/cm^3)	% TMD	Product Library BKWC		Product Library BKWS	
		Detonation		Detonation	
		Pressure (GPa)	Velocity (m/s)	Pressure (GPa)	Velocity (m/s)
1.7629	***100.0***	24.54	7671	24.65	7804
1.7500	*99.27*	24.07	7626	24.20	7755
1.7400	*98.70*	23.71	7591	23.86	7716
1.7300	*98.13*	23.36	7556	23.52	7678
1.7200	*97.57*	23.01	7521	23.19	7640
1.7100	*97.00*	22.66	7486	22.86	7602
1.7000	*96.43*	22.32	7450	22.53	7563
1.6900	*95.86*	21.98	7415	22.20	7525
1.6800	*95.30*	21.65	7380	21.88	7487
1.6700	*94.73*	21.32	7345	21.57	7449
1.6600	*94.16*	21.00	7310	21.26	7412

Table 3.9 Detonation pressure and velocity for different densities of MCX-6100 calculated with Cheetah 2.0.

Experimentally obtained detonation pressures and velocities are both lower than calculated by both product libraries. Best agreement between experimentally and calculated properties is obtained with the BKWC product library. The experimentally determined detonation pressure is 12-15 % lower than calculated by Cheetah. The detonation velocity is 4% lower than the calculated value for charges with diameter 35-37 mm.

4 Summary

Different samples of MCX-6100 have 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.

There are variations in quality of the casted test items with regard to density. Most items have a density of 96$\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-6100 CH 6079/13 seems relatively reproducible. 5 conical charges have been, tested giving a critical diameter of 19.1± 1.4 mm or 19.7 ± 0.8 mm if the 4 most equal measurements are included in the calculations.

Detonation velocities have been determined for both cylindrical charges with diameter 36±1 mm and for conical charges with largest diameter 30 mm. The detonation velocity varies with the density of the tested charges. Average velocity for the 4 test items with highest density is 7199±81 m/s (average density 1.71±0.02 g/cm^3). This result is 3-400 m/s lower than the theoretically calculated values with Cheetah 2.0. For the conical charge the detonation velocity for charge diameter between 24 mm and 27 mm is 6281 m/s and for charge diameter between 21 mm and 24 mm it is 4685 m/s.

Detonation pressure is measured by Plate Dent test for 6 test charges, giving an average pressure of 190±7 kbar. As for the detonation velocity this result is lower than the theoretically calculated value by Cheetah 2.0. The difference is approximately 30±10 kbar.

References

(1) STANAG 4439 JAIS (Edition 3) – Policy for introduction and assessment of Insensitive Munitions (IM), NSA/0337(2010)-JAIS/4439 17 March 2010.

(2) Gunnar Ove Nevstad: Intermediate Scale Gap test of MCX-6002, FFI-rapport-2015/02184, November 2015.

(3) Gunnar Ove Nevstad: Intermediate Scale Gap test of MCX-6100, FFI-rapport-2015/02183, 18 November 2015.

(4) Philip Samuels, Leila Zunino, Keyur Patel, Brian Travers, Erik Wrobel, Henry Grau, Charlie Patel; Characterization of 2,4-Dinitroanisole (DNAN), 2012 Insensitive Munitions & Energetic Materials Technology Symposium, Las Vegas, 14-17 May.

(5) Arthur Provatas, P J Davis: Characterization of 2,4-Dinitroanisole (DNAN) an Ingredients for use in low Sensitivity Melt-Cast Formulations, DSTO-TR1904.

(6) Virgil Fung, Mike Ervin, Brian Alexander, Charlie Patel, Philip Samuels: Development and Manufacture of an Insensitive Composition B Replacement Explosive IMX-104 for Mortar Applications; Insensitive Munitions & Energetic Materials Technology Symposium, Munich, 11-14 October.

(7) Sanjeev Singh, Lauren Jelinek, Philip Samuels, Anthony Di Stasio, Leila Zunino; IMX-104 Characterization for DoD Qualification, 2010 Insensitive Munitions & Energetic Materials Technology Symposium, Munich, 11-14 October.

(8) Leila Zunino, Philip Samuels, C Hu; IMX-104 Characterization for DoD Qualification, 2012 Insensitive Munitions & Energetic Materials Technology Symposium, Las Vegas, 14-17 May.

(9) Hartmut Badners and Carl-Otto Leiber: Method for the Determination of the Critical Diameter of High Velocity Detonation by Conical Geometry”, Propellants, Explosives, Pyrotechnics 17, 77-81, 1992.

(10) Gunnar Ove Nevstad: Introduction of ionization in probes to measure detonation velocity; FFI-rapport 2015/00178, 9 February 2015.

(11) Harry E. Cleaver: Pin Switch Instrument for microsecond Velocity Measurement. NSWC MP 88-172, 8 September 1988.

(12) Eriksen Svein, Skarbøvik Knut, Larsen Øivind, Hagen Norman (1984): Bestemmelse av detonasjonsparametre, FFI/NOTAT-84/4041, Unclassified.

(13) Gibbs&Popolato (1980): LASL Explosive Property Data, Los Alamos Data Center for Dynamic Material Properties

(14) Laurence E. Fried, W. Michael Howard, P. Clark Souers (1998): Cheetah 2.0 User's Manual, UCRL-MA-117541 Rev. 5; Energetic Materials Center Lawrence Livermore National Laboratory, 20 August.

(15) C Coulouarn, R Aumasson, P Lamy-Bracq, S Bulot: Energetic binders: DNAN vs TNT. Evaluation of melt-cast explosive compositions based on TNT and DNAN. ICT 2014, Kalsruhe, June 2014.

(16) Leila Zunino, Philip Samuels, C Hu; IMX-104 Characterization for DoD Qualification, 2012 Insensitive Munitions& Energetic Materials Technology Symposium, Las Vegas, 14-17 May.

Appendix A Certificate Plate Dent Plates

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

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

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

TENSILE TEST FROM 1/3 RADIUS

	REH MPa	RM MPa	A 5 %	Z %
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.

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Quality control
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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

MSA R-1447

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

Appendix B Control report HWC

Figure A.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	Bestillingsnummer	Rapportnummer
FFI Postboks 25 2007 Kjeller	V/ Gunnar Nevstad Bestillingsdato 16.01.14	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

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-6100

C.1 BKWC Product Library

C.1.1 TMD 1.7629 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 formation (cal/mol)	Mol. wt.	TMD (g/cc)	
DNAN24	32.00	25.37	36.44	-44455	198.13	1.55	$C_7H_6N_2O_5$
RDX	15.00	10.61	14.64	16496	222.13	1.81	$C_3H_6N_6O_6$
NTO	53.00	64.02	48.92	-24140	130.07	1.91	$C_2H_2N_4O_3$

Density = 1.7629 g/cc Mixture TMD = 1.7629 g/cc % TMD = 100.0000

The C-J condition:

The pressure	=	24.54 GPa
The volume	=	0.433 cc/g
The density	=	2.309 g/cc
The energy	=	2.90 kJ/cc explosive
The temperature	=	3405 K
The shock velocity	=	7.671 mm/us
The particle velocity	=	1.815 mm/us
The speed of sound	=	5.856 mm/us
Gamma	=	3.226

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	-0.86					
2.20	-4.73	98	75	63	52	109
4.10	-5.69	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	-6.99	98	74	67	58	90
80.00	-7.19	98	74	67	58	87
160.00	-7.36					

Freezing occurred at T = 1800.0 K and relative V = 1.744
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 = -7.951 kJ/cc
A = 815.26 GPa, B = 7.43 GPa, C = 1.22 GPa
R[1] = 4.86, R[2] = 1.10, omega = 0.35
RMS fitting error = 0.66 %

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 formation (cal/mol)	Mol. wt.	TMD (g/cc)	
DNAN24	32.00	25.37	36.44	-44455	198.13	1.55	$C_7H_6N_2O_5$
RDX	15.00	10.61	14.64	16496	222.13	1.81	$C_3H_6N_6O_6$
NTO	53.00	64.02	48.92	-24140	130.07	1.91	$C_2H_2N_4O_3$

Density = 1.7500 g/cc   Mixture TMD = 1.7629 g/cc   **% TMD = 99.2708**

The C-J condition:

The pressure	=	24.07 GPa
The volume	=	0.436 cc/g
The density	=	2.292 g/cc
The energy	=	2.85 kJ/cc explosive
The temperature	=	3409 K
The shock velocity	=	7.626 mm/us
The particle velocity	=	1.804 mm/us
The speed of sound	=	5.822 mm/us
Gamma	=	3.228

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	-4.67	96	74	63	52	107
4.10	-5.62	97	73	63	53	102
6.50	-6.03	97	73	64	54	99
10.00	-6.31	97	73	65	55	96
20.00	-6.65	97	73	65	56	93
40.00	-6.91	97	73	66	57	89
80.00	-7.12	97	73	66	58	86
160.00	-7.28					

Freezing occurred at T = 1800.0 K and relative V = 1.753
The mechanical energy of detonation = -7.541 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -7.541 kJ/cc

JWL Fit results:

E0 = -7.874 kJ/cc
A = 802.06 GPa, B = 7.32 GPa, C = 1.22 GPa
R[1] = 4.86, R[2] = 1.10, omega = 0.35
RMS fitting error = 0.66 %

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 formation (cal/mol)	Mol. wt.	TMD (g/cc)	
DNAN24	32.00	25.37	36.44	-44455	198.13	1.55	$C_7H_6N_2O_5$
RDX	15.00	10.61	14.64	16496	222.13	1.81	$C_3H_6N_6O_6$
NTO	53.00	64.02	48.92	-24140	130.07	1.91	$C_2H_2N_4O_3$

Density = 1.7400 g/cc   Mixture TMD = 1.7629 g/cc   **% TMD = 98.7035**

The C-J condition:

The pressure	=	23.71 GPa
The volume	=	0.439 cc/g
The density	=	2.279 g/cc
The energy	=	2.80 kJ/cc explosive
The temperature	=	3412 K
The shock velocity	=	7.591 mm/us
The particle velocity	=	1.795 mm/us
The speed of sound	=	5.796 mm/us
Gamma	=	3.228

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	-4.62	95	73	62	51	106
4.10	-5.57	96	72	63	53	101
6.50	-5.98	96	72	63	54	98
10.00	-6.26	96	72	64	55	95
20.00	-6.60	96	72	65	56	92
40.00	-6.85	96	72	65	56	89
80.00	-7.06	96	72	66	57	86
160.00	-7.22					

Freezing occurred at T = 1800.0 K and relative V = 1.761
The mechanical energy of detonation = -7.482 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -7.482 kJ/cc

JWL Fit results:

E0 = -7.814 kJ/cc
A = 791.74 GPa, B = 7.24 GPa, C = 1.21 GPa
R[1] = 4.87, R[2] = 1.10, omega = 0.35
RMS fitting error = 0.67 %

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 formation (cal/mol)	Mol. wt.	TMD (g/cc)	
DNAN24	32.00	25.37	36.44	-44455	198.13	1.55	$C_7H_6N_2O_5$
RDX	15.00	10.61	14.64	16496	222.13	1.81	$C_3H_6N_6O_6$
NTO	53.00	64.02	48.92	-24140	130.07	1.91	$C_2H_2N_4O_3$

Density = 1.7300 g/cc Mixture TMD = 1.7629 g/cc **% TMD = 98.1363**

The C-J condition:

The pressure	=	23.36 GPa
The volume	=	0.441 cc/g
The density	=	2.266 g/cc
The energy	=	2.76 kJ/cc explosive
The temperature	=	3415 K
The shock velocity	=	7.556 mm/us
The particle velocity	=	1.787 mm/us
The speed of sound	=	5.769 mm/us
Gamma	=	3.229

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	-0.83					
2.20	-4.57	94	72	61	50	105
4.10	-5.51	95	71	62	52	100
6.50	-5.92	95	71	63	53	97
10.00	-6.20	95	71	63	54	95
20.00	-6.54	95	71	64	55	91
40.00	-6.80	95	72	65	56	88
80.00	-7.00	95	72	65	57	85
160.00	-7.17					

Freezing occurred at T = 1800.0 K and relative V = 1.768
The mechanical energy of detonation = -7.424 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -7.424 kJ/cc

JWL Fit results:

E0 = -7.834 kJ/cc
A = 784.60 GPa, B = 7.22 GPa, C = 1.07 GPa
R[1] = 4.87, R[2] = 1.06, omega = 0.32
RMS fitting error = 0.88 %

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 formation (cal/mol)	Mol. wt.	TMD (g/cc)	
DNAN24	32.00	25.37	36.44	-44455	198.13	1.55	$C_7H_6N_2O_5$
RDX	15.00	10.61	14.64	16496	222.13	1.81	$C_3H_6N_6O_6$
NTO	53.00	64.02	48.92	-24140	130.07	1.91	$C_2H_2N_4O_3$

Density = 1.7200 g/cc Mixture TMD = 1.7629 g/cc **% TMD = 97.5690**

The C-J condition:

The pressure	=	23.01 GPa
The volume	=	0.444 cc/g
The density	=	2.253 g/cc
The energy	=	2.72 kJ/cc explosive
The temperature	=	3417 K
The shock velocity	=	7.521 mm/us
The particle velocity	=	1.778 mm/us
The speed of sound	=	5.742 mm/us
Gamma	=	3.229

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	-0.82					
2.20	-4.52	93	71	60	50	104
4.10	-5.46	94	71	62	52	99
6.50	-5.86	94	71	62	53	96
10.00	-6.14	94	71	63	54	94
20.00	-6.48	94	71	64	55	90
40.00	-6.74	94	71	64	55	87
80.00	-6.94	94	71	65	56	84
160.00	-7.11					

Freezing occurred at T = 1800.0 K and relative V = 1.775
The mechanical energy of detonation = -7.365 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -7.365 kJ/cc

JWL Fit results:

E0 = -7.696 kJ/cc
A = 770.79 GPa, B = 7.09 GPa, C = 1.21 GPa
R[1] = 4.88, R[2] = 1.10, omega = 0.35
RMS fitting error = 0.67 %

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 formation (cal/mol)	Mol. wt.	TMD (g/cc)	
DNAN24	32.00	25.37	36.44	-44455	198.13	1.55	$C_7H_6N_2O_5$
RDX	15.00	10.61	14.64	16496	222.13	1.81	$C_3H_6N_6O_6$
NTO	53.00	64.02	48.92	-24140	130.07	1.91	$C_2H_2N_4O_3$

Density = 1.7100 g/cc   Mixture TMD = 1.7629 g/cc   **% TMD = 97.0018**

The C-J condition:

The pressure	=	22.66 GPa
The volume	=	0.447 cc/g
The density	=	2.240 g/cc
The energy	=	2.68 kJ/cc explosive
The temperature	=	3420 K
The shock velocity	=	7.486 mm/us
The particle velocity	=	1.770 mm/us
The speed of sound	=	5.715 mm/us
Gamma	=	3.229

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	-4.47	92	70	60	49	102
4.10	-5.40	93	70	61	51	98
6.50	-5.81	93	70	62	52	95
10.00	-6.09	93	70	62	53	93
20.00	-6.43	94	70	63	54	90
40.00	-6.68	93	70	64	55	86
80.00	-6.88	93	70	64	56	84
160.00	-7.05					

Freezing occurred at T = 1800.0 K and relative V = 1.782
The mechanical energy of detonation = -7.307 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -7.307 kJ/cc

JWL Fit results:

E0 = -7.637 kJ/cc
A = 759.78 GPa, B = 7.00 GPa, C = 1.21 GPa
R[1] = 4.88, R[2] = 1.10, omega = 0.35
RMS fitting error = 0.67 %

C.1.7 Density 1.700 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 formation (cal/mol)	Mol. wt.	TMD (g/cc)	
DNAN24	32.00	25.37	36.44	-44455	198.13	1.55	$C_7H_6N_2O_5$
RDX	15.00	10.61	14.64	16496	222.13	1.81	$C_3H_6N_6O_6$
NTO	53.00	64.02	48.92	-24140	130.07	1.91	$C_2H_2N_4O_3$

Density = 1.7000 g/cc Mixture TMD = 1.7629 g/cc **% TMD = 96.4345**

The C-J condition:

The pressure	=	22.32 GPa
The volume	=	0.449 cc/g
The density	=	2.227 g/cc
The energy	=	2.64 kJ/cc explosive
The temperature	=	3422 K
The shock velocity	=	7.450 mm/us
The particle velocity	=	1.762 mm/us
The speed of sound	=	5.688 mm/us
Gamma	=	3.228

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	-0.80					
2.20	-4.42	91	70	59	49	101
4.10	-5.35	92	69	60	51	97
6.50	-5.75	92	69	61	52	94
10.00	-6.03	93	69	62	53	92
20.00	-6.37	93	70	62	54	89
40.00	-6.62	93	70	63	55	86
80.00	-6.83	93	70	64	55	83
160.00	-6.99					

Freezing occurred at T = 1800.0 K and relative V = 1.789
The mechanical energy of detonation = -7.249 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -7.249 kJ/cc

JWL Fit results:

E0 = -7.654 kJ/cc
A = 752.54 GPa, B = 6.99 GPa, C = 1.07 GPa
R[1] = 4.88, R[2] = 1.06, omega = 0.32
RMS fitting error = 0.88 %

C.1.8 Density 1.690 g/cm³

Product library title: **bkwc**

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)	
DNAN24	32.00	25.37	36.44	-44455	198.13	1.55	$C_7H_6N_2O_5$
RDX	15.00	10.61	14.64	16496	222.13	1.81	$C_3H_6N_6O_6$
NTO	53.00	64.02	48.92	-24140	130.07	1.91	$C_2H_2N_4O_3$

Density = 1.6900 g/cc Mixture TMD = 1.7629 g/cc **% TMD = 95.8672**

The C-J condition:

The pressure	=	21.98 GPa
The volume	=	0.452 cc/g
The density	=	2.214 g/cc
The energy	=	2.60 kJ/cc explosive
The temperature	=	3424 K
The shock velocity	=	7.415 mm/us
The particle velocity	=	1.754 mm/us
The speed of sound	=	5.661 mm/us
Gamma	=	3.228

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	-0.79					
2.20	-4.37	90	69	59	48	100
4.10	-5.30	91	69	60	50	96
6.50	-5.70	91	69	61	51	93
10.00	-5.98	92	69	61	52	91
20.00	-6.31	92	69	62	53	88
40.00	-6.57	92	69	63	54	85
80.00	-6.77	92	69	63	55	82
160.00	-6.93					

Freezing occurred at T = 1800.0 K and relative V = 1.796
The mechanical energy of detonation = -7.191 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -7.191 kJ/cc

JWL Fit results:

E0 = -7.518 kJ/cc
A = 738.06 GPa, B = 6.84 GPa, C = 1.20 GPa
R[1] = 4.88, R[2] = 1.10, omega = 0.35
RMS fitting error = 0.68 %

C.1.9 Density 1.680 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 formation (cal/mol)	Mol. wt.	TMD (g/cc)	
DNAN24	32.00	25.37	36.44	-44455	198.13	1.55	$C_7H_6N_2O_5$
RDX	15.00	10.61	14.64	16496	222.13	1.81	$C_3H_6N_6O_6$
NTO	53.00	64.02	48.92	-24140	130.07	1.91	$C_2H_2N_4O_3$

Density = 1.6800 g/cc Mixture TMD = 1.7629 g/cc **% TMD = 95.3000**

The C-J condition:

The pressure	=	21.65 GPa
The volume	=	0.454 cc/g
The density	=	2.201 g/cc
The energy	=	2.56 kJ/cc explosive
The temperature	=	3426 K
The shock velocity	=	7.380 mm/us
The particle velocity	=	1.746 mm/us
The speed of sound	=	5.634 mm/us
Gamma	=	3.227

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	-0.78					
2.20	-4.32	89	68	58	48	99
4.10	-5.24	90	68	59	50	95
6.50	-5.64	91	68	60	51	92
10.00	-5.92	91	68	61	52	90
20.00	-6.26	91	68	61	53	87
40.00	-6.51	91	69	62	54	84
80.00	-6.71	91	69	63	54	81
160.00	-6.88					

Freezing occurred at T = 1800.0 K and relative V = 1.802
The mechanical energy of detonation = -7.133 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -7.133 kJ/cc

JWL Fit results:

E0 = -7.535 kJ/cc
A = 730.76 GPa, B = 6.83 GPa, C = 1.06 GPa
R[1] = 4.89, R[2] = 1.06, omega = 0.32
RMS fitting error = 0.88 %

C.1.10 Density 1.670 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 formation (cal/mol)	Mol. wt.	TMD (g/cc)	
DNAN24	32.00	25.37	36.44	-44455	198.13	1.55	$C_7H_6N_2O_5$
RDX	15.00	10.61	14.64	16496	222.13	1.81	$C_3H_6N_6O_6$
NTO	53.00	64.02	48.92	-24140	130.07	1.91	$C_2H_2N_4O_3$

Density = 1.6700 g/cc Mixture TMD = 1.7629 g/cc **% TMD = 94.7327**

The C-J condition:

The pressure	=	21.32 GPa
The volume	=	0.457 cc/g
The density	=	2.188 g/cc
The energy	=	2.52 kJ/cc explosive
The temperature	=	3429 K
The shock velocity	=	7.345 mm/us
The particle velocity	=	1.738 mm/us
The speed of sound	=	5.607 mm/us
Gamma	=	3.225

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	-0.77					
2.20	-4.28	88	67	57	47	98
4.10	-5.19	89	67	59	49	94
6.50	-5.59	90	67	59	50	91
10.00	-5.87	90	67	60	51	89
20.00	-6.20	90	68	61	52	86
40.00	-6.45	90	68	62	53	83
80.00	-6.66	90	68	62	54	81
160.00	-6.82					

Freezing occurred at T = 1800.0 K and relative V = 1.809
The mechanical energy of detonation = -7.075 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -7.075 kJ/cc

JWL Fit results:

E0 = -7.476 kJ/cc
A = 719.66 GPa, B = 6.75 GPa, C = 1.06 GPa
R[1] = 4.89, R[2] = 1.06, omega = 0.32
RMS fitting error = 0.88 %

C.1.11 Density 1.660 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 formation (cal/mol)	Mol. wt.	TMD (g/cc)	
DNAN24	32.00	25.37	36.44	-44455	198.13	1.55	$C_7H_6N_2O_5$
RDX	15.00	10.61	14.64	16496	222.13	1.81	$C_3H_6N_6O_6$
NTO	53.00	64.02	48.92	-24140	130.07	1.91	$C_2H_2N_4O_3$

Density = 1.6600 g/cc Mixture TMD = 1.7629 g/cc **% TMD = 94.1654**

The C-J condition:

The pressure	=	21.00 GPa
The volume	=	0.460 cc/g
The density	=	2.175 g/cc
The energy	=	2.49 kJ/cc explosive
The temperature	=	3430 K
The shock velocity	=	7.310 mm/us
The particle velocity	=	1.731 mm/us
The speed of sound	=	5.579 mm/us
Gamma	=	3.224

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	-0.76					
2.20	-4.23	87	67	57	47	97
4.10	-5.14	88	67	58	49	93
6.50	-5.54	89	67	59	50	91
10.00	-5.81	89	67	59	51	89
20.00	-6.14	89	67	60	52	86
40.00	-6.40	89	67	61	53	83
80.00	-6.60	90	68	62	53	80
160.00	-6.76					

Freezing occurred at T = 1800.0 K and relative V = 1.816
The mechanical energy of detonation = -7.018 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -7.018 kJ/cc

JWL Fit results:

E0 = -7.416 kJ/cc
A = 708.58 GPa, B = 6.67 GPa, C = 1.06 GPa
R[1] = 4.89, R[2] = 1.06, omega = 0.32
RMS fitting error = 0.88 %

C.2 BKWS Product Library

C.2.1 TMD 1.769 g/cm^3

```
Product library title: bkws

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)	
DNAN24	32.00	25.37	36.44	-44455	198.13	1.55	$C_7H_6N_2O_5$
RDX	15.00	10.61	14.64	16496	222.13	1.81	$C_3H_6N_6O_6$
NTO	53.00	64.02	48.92	-24140	130.07	1.91	$C_2H_2N_4O_3$

```
Product library title: bkws library


Density  =  1.7629 g/cc   Mixture TMD =  1.7629 g/cc   % TMD = 100.0000


The C-J condition:
The pressure          =          24.65 GPa
The volume            =          0.437 cc/g
The density           =          2.288 g/cc
The energy            =           2.83 kJ/cc explosive
The temperature       =           3425 K
The shock velocity    =          7.804 mm/us
The particle velocity =          1.792 mm/us
The speed of sound    =          6.012 mm/us
Gamma                 =          3.356
```

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	-0.88					
2.20	-4.92	101	78	66	54	113
4.10	-5.92	102	77	67	56	107
6.50	-6.34	102	76	67	57	104
10.00	-6.62	102	76	68	58	101
20.00	-6.96	101	76	68	59	97
40.00	-7.21	101	76	69	59	93
80.00	-7.41	101	76	69	60	90
160.00	-7.58					

```
Freezing occurred at T =     1800.0 K and relative V =   1.762
The mechanical energy of detonation =     -7.829 kJ/cc
The thermal energy of detonation    =     -0.000 kJ/cc
The total energy of detonation      =     -7.829 kJ/cc

JWL Fit results:
E0   =       -8.227 kJ/cc
A    =       930.73 GPa, B    =      8.00 GPa , C     =         1.06 GPa
R[1] =         4.96,    R[2] =      1.06,      omega =         0.32
RMS fitting error =   1.08 %
```

C.2.2 Density 1.750 g/cm^3

Product library title: **bkws**

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)	
DNAN24	32.00	25.37	36.44	-44455	198.13	1.55	$C_7H_6N_2O_5$
RDX	15.00	10.61	14.64	16496	222.13	1.81	$C_3H_6N_6O_6$
NTO	53.00	64.02	48.92	-24140	130.07	1.91	$C_2H_2N_4O_3$

Density = 1.7500 g/cc   Mixture TMD = 1.7629 g/cc   **% TMD = 99.2708**

The C-J condition:

The pressure	=	24.20 GPa
The volume	=	0.440 cc/g
The density	=	2.273 g/cc
The energy	=	2.78 kJ/cc explosive
The temperature	=	3430 K
The shock velocity	=	7.755 mm/us
The particle velocity	=	1.783 mm/us
The speed of sound	=	5.971 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	-0.86					
2.20	-4.86	100	76	65	54	111
4.10	-5.85	101	76	66	55	106
6.50	-6.26	101	75	66	56	103
10.00	-6.55	100	75	67	57	100
20.00	-6.88	100	75	68	58	96
40.00	-7.14	100	75	68	59	92
80.00	-7.34	100	75	69	59	89
160.00	-7.50					

Freezing occurred at T = 1800.0 K and relative V = 1.772
The mechanical energy of detonation = -7.756 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -7.756 kJ/cc

JWL Fit results:

E0 = -8.064 kJ/cc
A = 925.39 GPa, B = 8.14 GPa, C = 1.22 GPa
R[1] = 5.00, R[2] = 1.11, omega = 0.36
RMS fitting error = 0.86 %

C.2.3 Density 1.740 g/cm^3

Product library title: **bkws**

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)	
DNAN24	32.00	25.37	36.44	-44455	198.13	1.55	$C_7H_6N_2O_5$
RDX	15.00	10.61	14.64	16496	222.13	1.81	$C_3H_6N_6O_6$
NTO	53.00	64.02	48.92	-24140	130.07	1.91	$C_2H_2N_4O_3$

Density = 1.7400 g/cc   Mixture TMD = 1.7629 g/cc   **% TMD = 98.7035**

The C-J condition:

The pressure	=	23.86 GPa
The volume	=	0.442 cc/g
The density	=	2.261 g/cc
The energy	=	2.75 kJ/cc explosive
The temperature	=	3434 K
The shock velocity	=	7.716 mm/us
The particle velocity	=	1.777 mm/us
The speed of sound	=	5.939 mm/us
Gamma	=	3.342

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	-4.81	99	76	64	53	110
4.10	-5.79	100	75	65	55	105
6.50	-6.21	100	75	66	56	102
10.00	-6.49	100	75	66	57	99
20.00	-6.83	99	75	67	57	95
40.00	-7.08	99	75	68	58	92
80.00	-7.28	99	75	68	59	88
160.00	-7.44					

Freezing occurred at T = 1800.0 K and relative V = 1.779
The mechanical energy of detonation = -7.699 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -7.699 kJ/cc

JWL Fit results:

E0 = -8.093 kJ/cc
A = 890.95 GPa, B = 7.80 GPa, C = 1.06 GPa
R[1] = 4.96, R[2] = 1.06, omega = 0.32
RMS fitting error = 1.07 %

C.2.4 Density 1.730 g/cm^3

Product library title: **bkws**

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)	
DNAN24	32.00	25.37	36.44	-44455	198.13	1.55	$C_7H_6N_2O_5$
RDX	15.00	10.61	14.64	16496	222.13	1.81	$C_3H_6N_6O_6$
NTO	53.00	64.02	48.92	-24140	130.07	1.91	$C_2H_2N_4O_3$

Density = 1.7300 g/cc   Mixture TMD = 1.7629 g/cc   **% TMD = 98.1363**

The C-J condition:

The pressure	=	23.52 GPa
The volume	=	0.445 cc/g
The density	=	2.249 g/cc
The energy	=	2.71 kJ/cc explosive
The temperature	=	3438 K
The shock velocity	=	7.678 mm/us
The particle velocity	=	1.771 mm/us
The speed of sound	=	5.907 mm/us
Gamma	=	3.336

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	-4.76	98	75	64	53	109
4.10	-5.73	99	74	65	54	104
6.50	-6.15	99	74	65	55	101
10.00	-6.43	99	74	66	56	98
20.00	-6.77	99	74	66	57	94
40.00	-7.02	98	74	67	58	91
80.00	-7.22	98	74	67	58	88
160.00	-7.38					

Freezing occurred at T = 1800.0 K and relative V = 1.787
The mechanical energy of detonation = -7.642 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -7.642 kJ/cc

JWL Fit results:

E0 = -8.035 kJ/cc
A = 873.86 GPa, B = 7.71 GPa, C = 1.06 GPa
R[1] = 4.95, R[2] = 1.05, omega = 0.32
RMS fitting error = 1.07 %

C.2.5 Density 1.720 g/cm^3

Product library title: **bkws**

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)	
DNAN24	32.00	25.37	36.44	-44455	198.13	1.55	$C_7H_6N_2O_5$
RDX	15.00	10.61	14.64	16496	222.13	1.81	$C_3H_6N_6O_6$
NTO	53.00	64.02	48.92	-24140	130.07	1.91	$C_2H_2N_4O_3$

Density = 1.7200 g/cc   Mixture TMD = 1.7629 g/cc   **% TMD = 97.5690**

The C-J condition:

The pressure	=	23.19 GPa
The volume	=	0.447 cc/g
The density	=	2.237 g/cc
The energy	=	2.68 kJ/cc explosive
The temperature	=	3442 K
The shock velocity	=	7.640 mm/us
The particle velocity	=	1.765 mm/us
The speed of sound	=	5.875 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	-0.83					
2.20	-4.70	97	74	63	52	108
4.10	-5.68	98	74	64	54	103
6.50	-6.09	98	73	65	55	100
10.00	-6.37	98	73	65	56	97
20.00	-6.71	98	73	66	56	94
40.00	-6.96	97	73	66	57	90
80.00	-7.16	97	73	67	58	87
160.00	-7.33					

Freezing occurred at T = 1800.0 K and relative V = 1.795
The mechanical energy of detonation = -7.584 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -7.584 kJ/cc

JWL Fit results:

E0 = -7.977 kJ/cc
A = 856.97 GPa, B = 7.62 GPa, C = 1.06 GPa
R[1] = 4.95, R[2] = 1.05, omega = 0.32
RMS fitting error = 1.07 %

C.2.6 Density 1.710 g/cm^3

Product library title: **bkws**

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)	
DNAN24	32.00	25.37	36.44	-44455	198.13	1.55	$C_7H_6N_2O_5$
RDX	15.00	10.61	14.64	16496	222.13	1.81	$C_3H_6N_6O_6$
NTO	53.00	64.02	48.92	-24140	130.07	1.91	$C_2H_2N_4O_3$

Density = 1.7100 g/cc Mixture TMD = 1.7629 g/cc **% TMD = 97.0018**

The C-J condition:

```
The pressure          =          22.86 GPa
The volume            =          0.450 cc/g
The density           =          2.225 g/cc
The energy            =           2.64 kJ/cc explosive
The temperature       =           3446 K
The shock velocity    =          7.602 mm/us
The particle velocity =          1.758 mm/us
The speed of sound    =          5.843 mm/us
Gamma                 =          3.323
```

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	-0.82					
2.20	-4.66	96	73	62	51	107
4.10	-5.62	97	73	63	53	102
6.50	-6.04	97	73	64	54	99
10.00	-6.32	97	73	65	55	96
20.00	-6.65	97	73	65	56	93
40.00	-6.90	97	73	66	57	89
80.00	-7.10	96	73	66	58	86
160.00	-7.27					

```
Freezing occurred at T =     1800.0 K and relative V =   1.802
The mechanical energy of detonation =     -7.527 kJ/cc
The thermal energy of detonation    =     -0.000 kJ/cc
The total energy of detonation      =     -7.527 kJ/cc
```

JWL Fit results:

```
E0   =       -7.832 kJ/cc
A    =       861.61 GPa, B    =         7.85 GPa,  C     =     1.21 GPa
R[1] =         5.00,     R[2] =         1.10,      omega =     0.35
RMS fitting error =   0.86 %
```

C.2.7 Density 1.700 g/cm^3

Product library title: **bkws**

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)	
DNAN24	32.00	25.37	36.44	-44455	198.13	1.55	$C_7H_6N_2O_5$
RDX	15.00	10.61	14.64	16496	222.13	1.81	$C_3H_6N_6O_6$
NTO	53.00	64.02	48.92	-24140	130.07	1.91	$C_2H_2N_4O_3$

Density = 1.7000 g/cc   Mixture TMD = 1.7629 g/cc   % **TMD = 96.4345**

The C-J condition:

The pressure	=	22.53 GPa
The volume	=	0.452 cc/g
The density	=	2.213 g/cc
The energy	=	2.61 kJ/cc explosive
The temperature	=	3450 K
The shock velocity	=	7.563 mm/us
The particle velocity	=	1.752 mm/us
The speed of sound	=	5.811 mm/us
Gamma	=	3.317

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	-4.61	95	73	62	51	106
4.10	-5.57	96	72	63	53	101
6.50	-5.98	96	72	63	54	98
10.00	-6.26	96	72	64	55	95
20.00	-6.60	96	72	65	56	92
40.00	-6.85	96	72	65	56	89
80.00	-7.05	96	72	66	57	86
160.00	-7.21					

Freezing occurred at T = 1800.0 K and relative V = 1.810
The mechanical energy of detonation = -7.470 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -7.470 kJ/cc

JWL Fit results:

E0 = -7.774 kJ/cc
A = 844.66 GPa, B = 7.76 GPa, C = 1.21 GPa
R[1] = 5.00, R[2] = 1.10, omega = 0.35
RMS fitting error = 0.85 %

C.2.8 Density 1.690 g/cm^3

Product library title: **bkws**

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)	
DNAN24	32.00	25.37	36.44	-44455	198.13	1.55	$C_7H_6N_2O_5$
RDX	15.00	10.61	14.64	16496	222.13	1.81	$C_3H_6N_6O_6$
NTO	53.00	64.02	48.92	-24140	130.07	1.91	$C_2H_2N_4O_3$

Density = 1.6900 g/cc Mixture TMD = 1.7629 g/cc **% TMD = 95.8672**

The C-J condition:

The pressure	=	22.20 GPa
The volume	=	0.454 cc/g
The density	=	2.201 g/cc
The energy	=	2.58 kJ/cc explosive
The temperature	=	3454 K
The shock velocity	=	7.525 mm/us
The particle velocity	=	1.746 mm/us
The speed of sound	=	5.779 mm/us
Gamma	=	3.310

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	-4.56	94	72	61	50	105
4.10	-5.52	95	71	62	52	100
6.50	-5.93	95	71	63	53	97
10.00	-6.20	95	71	63	54	95
20.00	-6.54	95	71	64	55	91
40.00	-6.79	95	71	65	56	88
80.00	-6.99	95	72	65	57	85
160.00	-7.15					

Freezing occurred at T = 1800.0 K and relative V = 1.817
The mechanical energy of detonation = -7.413 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -7.413 kJ/cc

JWL Fit results:

E0 = -7.801 kJ/cc
A = 806.97 GPa, B = 7.36 GPa, C = 1.05 GPa
R[1] = 4.94, R[2] = 1.05, omega = 0.32
RMS fitting error = 1.07 %

C.2.9 Density 1.680 g/cm^3

Product library title: **bkws**

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)	
DNAN24	32.00	25.37	36.44	-44455	198.13	1.55	$C_7H_6N_2O_5$
RDX	15.00	10.61	14.64	16496	222.13	1.81	$C_3H_6N_6O_6$
NTO	53.00	64.02	48.92	-24140	130.07	1.91	$C_2H_2N_4O_3$

Density = 1.6800 g/cc Mixture TMD = 1.7629 g/cc **% TMD = 95.3000**

The C-J condition:

The pressure	=	21.88 GPa
The volume	=	0.457 cc/g
The density	=	2.189 g/cc
The energy	=	2.54 kJ/cc explosive
The temperature	=	3458 K
The shock velocity	=	7.487 mm/us
The particle velocity	=	1.740 mm/us
The speed of sound	=	5.748 mm/us
Gamma	=	3.304

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	-0.80					
2.20	-4.51	93	71	60	50	103
4.10	-5.46	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	-6.48	94	71	64	55	90
40.00	-6.73	94	71	64	55	87
80.00	-6.93	94	71	65	56	84
160.00	-7.09					

Freezing occurred at T = 1800.0 K and relative V = 1.824
The mechanical energy of detonation = -7.356 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -7.356 kJ/cc

JWL Fit results:

E0 = -7.658 kJ/cc
A = 813.46 GPa, B = 7.61 GPa, C = 1.20 GPa
R[1] = 5.00, R[2] = 1.10, omega = 0.35
RMS fitting error = 0.85 %

C.2.10 Density 1.670 g/cm^3

Product library title: **bkws**

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)	
DNAN24	32.00	25.37	36.44	-44455	198.13	1.55	$C_7H_6N_2O_5$
RDX	15.00	10.61	14.64	16496	222.13	1.81	$C_3H_6N_6O_6$
NTO	53.00	64.02	48.92	-24140	130.07	1.91	$C_2H_2N_4O_3$

Density = 1.6700 g/cc Mixture TMD = 1.7629 g/cc **% TMD = 94.7327**

The C-J condition:

The pressure	=	21.57 GPa
The volume	=	0.459 cc/g
The density	=	2.177 g/cc
The energy	=	2.51 kJ/cc explosive
The temperature	=	3462 K
The shock velocity	=	7.449 mm/us
The particle velocity	=	1.734 mm/us
The speed of sound	=	5.716 mm/us
Gamma	=	3.297

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	-0.79					
2.20	-4.46	92	70	60	49	102
4.10	-5.41	93	70	61	51	98
6.50	-5.82	93	70	62	52	95
10.00	-6.09	93	70	62	53	93
20.00	-6.43	94	70	63	54	90
40.00	-6.68	93	70	64	55	86
80.00	-6.87	93	70	64	56	83
160.00	-7.04					

Freezing occurred at T = 1800.0 K and relative V = 1.832
The mechanical energy of detonation = -7.299 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -7.299 kJ/cc

JWL Fit results:

E0 = -7.600 kJ/cc
A = 797.84 GPa, B = 7.53 GPa, C = 1.20 GPa
R[1] = 5.00, R[2] = 1.10, omega = 0.35
RMS fitting error = 0.85 %

C.2.11 Density 1.660 g/cm^3

Product library title: **bkws**

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)	
DNAN24	32.00	25.37	36.44	-44455	198.13	1.55	$C_7H_6N_2O_5$
RDX	15.00	10.61	14.64	16496	222.13	1.81	$C_3H_6N_6O_6$
NTO	53.00	64.02	48.92	-24140	130.07	1.91	$C_2H_2N_4O_3$

Density = 1.6600 g/cc Mixture TMD = 1.7629 g/cc **% TMD = 94.1654**

The C-J condition:

The pressure	=	21.26 GPa
The volume	=	0.462 cc/g
The density	=	2.165 g/cc
The energy	=	2.48 kJ/cc explosive
The temperature	=	3465 K
The shock velocity	=	7.412 mm/us
The particle velocity	=	1.728 mm/us
The speed of sound	=	5.684 mm/us
Gamma	=	3.290

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	-0.78					
2.20	-4.41	91	69	59	49	101
4.10	-5.36	92	69	60	51	97
6.50	-5.76	92	69	61	52	94
10.00	-6.04	93	69	62	53	92
20.00	-6.37	93	70	63	54	89
40.00	-6.62	93	70	63	54	86
80.00	-6.82	93	70	64	55	83
160.00	-6.98					

Freezing occurred at T = 1800.0 K and relative V = 1.839
The mechanical energy of detonation = -7.242 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -7.242 kJ/cc

JWL Fit results:

E0 = -7.542 kJ/cc
A = 782.35 GPa, B = 7.45 GPa, C = 1.20 GPa
R[1] = 5.00, R[2] = 1.10, omega = 0.35
RMS fitting error = 0.85 %