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English summary

Knowledge about properties of explosive composition is important regardless of the applications. The performance of explosive compositions depends on detonation velocity and detonation pressure. The munition sensitivity depends on the critical diameter of the explosive filling in order to fulfill the IM requirements. The MCX-6002 and MCX-8001 studied in this report are new compositions developed with increased critical diameter to withstand shock threats from bullet attack, fragment impact, sympathetic detonation or shaped charge jet attack.

The explosive compositions MCX-6002 and MCX-8001 are developed and produced by Chemring Nobel. They are melt-cast compositions for application as filling in large caliber munitions like 120 mm and 155 mm shells. We have characterized MCX-6002 and MCX-8001 due to the potential for utilisation in these ammunition types. Both compositions have TNT as binder. The solid filler is a mix of NTO and RDX/HMX. Nominal content for MCX-6002 is NTO/TNT/RDX (51/34/15) and for MCX-8001 NTO/TNT/HMX (52/36/12).

MCX-6002 and MCX-8001 have been characterized with regards to critical diameter, detonation velocity and detonation pressure. Cylindrical charges with diameter from 11 mm to 37 mm were casted as test items for the tests. The quality of the charges was examined by X-ray, showing inclusion of air in all charges. This is porosity and pores/bubbles in the structure. Empty space was also observed in charges with a large diameter. However, the charges casted for detonation velocity and detonation pressure determinations had in the bottom a quality that could justify testing.

To test the critical diameter of MCX-6002, cylindrical charges of five different diameters were glued together to three test items with diameter from 11 mm to 26 mm. The test results showed a critical diameter smaller than 11 mm. Three conical charges with diameter from 30 mm to 3-4 mm were casted and tested. These gave an average critical diameter of 10 mm. To test the critical diameter of MCX-8001, three test items with diameter from 11 mm to 26 mm glued together from five cylindrical charges of different diameters were used. All test items had a critical diameter smaller than 11 mm.

Detonation velocity and pressure were tested with charges having diameter of 36 ± 2 mm. For both MCX-6002 and MCX-8001, four charges were casted. Only the part of the charges having acceptable density was tested. Measured detonation velocities MCX-6002 were as follows: cast No. 1 7964 m/s (ρ =1.78 g/cm^3), cast No. 2 7983 m/s (ρ =1.785 g/cm^3), cast No. 3 7700 m/s (ρ =1.79 g/cm^3) and for cast No. 4 7859 m/s (ρ=1.796 g/cm^3). Average experimentally measured detonation velocity is not very different from what is theoretically calculated. Two tests of detonation pressure gave an average detonation pressure of 244.3 kbar, a result slightly lower than what is theoretically calculated.

Measured detonation velocities for MCX-8001 were: cast No. 1 7836 m/s (ρ =1.768 g/cm^3), cast No. 2 7700 m/s (ρ =1.781 g/cm^3), cast No. 3 7426 m/s (ρ=1.758 g/cm^3) and 7790 m/s (ρ =1.778 g/cm^3) and cast No. 4 7842 m/s (ρ =1.786 g/cm^3). The average detonation velocity obtained experimentally is slightly below what is theoretically calculated. Two tests gave average detonation pressure of 245.8 kbar, slightly below what is theoretically calculated.

Sammendrag

Uavhengig av hva et sprengstoff skal brukes til, er det noen egenskaper som er viktige å ha kjennskap til. Virkningen til sprengstoff er avhengig av egenskaper som detonasjonshastighet og detonasjonstrykk, mens ammunisjonens følsomhet er avhengig av egenskaper som kritisk diameter for å tilfredsstille kravet til IM. MCX-6002 og MCX-8001 er to nyutviklede komposisjoner med økt kritisk diameter. Hovedtrusselen for IM-testene *bullet attack*, *fragment impact*, *sympathetic detonation* og *shaped charge jet attack* er sjokk som gir sjokkinitiering av sprengstoffet.

De testede komposisjonene er utviklet og produsert av Chemring Nobel. De er smeltestøpte komposisjoner som kan anvendes som hovedfylling i større kalibre som 120 mm og 155 mm granater. Vi har karakterisert komposisjonene utfra deres potensiale for bruk i denne type ammunisjon. MCX-6002 og MCX-8001 har TNT som bindemiddel. Faststoffet er en blanding av NTO og RDX for MCX-6002 og NTO og HMX for MCX-8001. Nominell sammensetning for MCX-6002 er NTO/DNAN/RDX (51/34/15) og for MCX-8001 NTO/DNAN/HMX (52/36/12).

I denne rapporten har ulike prøver av MCX-6002 og MCX-8001 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. Sylindriske ladninger med diameter fra 11mm til 37 mm er støpt for disse testene. Kvaliteten på ladningene ble undersøkt med røntgen. Røntgenbildene viser inneslutning av luft i alle legemene. Inneslutningene er observert som porøsitet og porer. For legemene med størst diameter kan også tomme rom observeres. Men alle legemene støpt for bestemmelse av detonasjonshastighet og detonasjonstrykk har akseptabel kvalitet i nedre halvdel, noe som rettferdiggjorde testing.

For bestemmelse av kritisk diameter til MCX-6002 ble tre testenheter, bestående av fem sylindriske legemer med diameter fra 11mm til 26 mm, limt sammen og testet. Testresultatet viste en kritisk diameter mindre enn 11 mm. Tre koniske legemer med diameter fra 30 mm til 3-4 mm ble også støpt og testet. Disse ga en kritisk diameter på 10 mm. For MCX-8001 ble tre testenheter, bestående av fem sylindriske legemer med diameter fra 11 mm til 26 mm, limt sammen og testet. Alle testenhetene hadde en kritisk diameter mindre enn 11 mm.

Detonasjonshastighet og trykk ble målt for ladninger med diameter 36$\pm$2 mm. 4 ladninger ble testet både for MCX-6002 og MCX-8001. Kun den delen av ladningene med akseptabel tetthet ble benyttet. Målte detonasjonshastigheter for MCX-6002 var: støp 1 7964 m/s (ρ =1.78 g/cm^3), støp 2 7983 m/s (ρ =1.785 g/cm^3), støp 3 7700 m/s (ρ =1.79 g/cm^3) og støp 4 7859 m/s (ρ=1.796 g/cm^3). Gjennomsnittlig målt detonasjonshastighet avviker lite fra det som er teoretisk beregnet. To målinger av detonasjonstrykket ga 244.3 kbar, et resultat litt under det teoretisk beregnede.

Målte detonasjonshastigheter for MCX-8001 var: støp 1 7836 m/s (ρ =1.768 g/cm^3), støp 2 7700 m/s (ρ =1.781 g/cm^3), støp 3 7426 m/s (ρ=1.758 g/cm^3) og 7790 m/s (ρ =1.778 g/cm^3) og støp 4 7842 m/s (ρ =1.786 g/cm^3). Gjennomsnittlig målt detonasjonshastighet er litt lavere enn det som er teoretisk beregnet. To målinger av detonasjonstrykket ga 245.8 kbar, litt under det som er teoretisk beregnet.

Contents

Abbreviations

BAMO	3,3-Bis-azidomethyl oxetane
BKWC	Becker-Kistiakowsky-Wilson C (LLNL library)
BKWS	Becker-Kistiakowsky-Wilson S (Baer/Hobbs library)
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-trizacyclohexane
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 in addition to pressed compositions containing GA/BAMO polymers have been studied. Norway's main activity in the project was on synthesizing GA/BAMO polymers suitable for coating nitramine crystals for production of press granules for press filling of munitions units or production of pressed charges.

Norway was the only country that used the energetic binder as binder for explosive charges (1). Italy and Germany used their polymers as binders in propellant formulations (1-3). The compositions 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 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 fillers preferentially for large caliber munitions. By using compounds as NTO and DNAN/TNT in the main explosive fillings, it will be possible to fulfil the IM requirements given in STANAG 4439 (4). Of the 4 compositions, two have TNT and two have DNAN as binder. The filler is either NTO/RDX or NTO/HMX. These compositions have in addition to the fragmentation performance been characterized for important properties as detonation velocity, detonation pressure and critical diameter. In addition shock sensitivity for the two NTO/RDX compositions has been determined (5, 6). The two DNAN compositions were characterized in reference (7) and (8) with regard to detonation velocity, detonation pressure and critical diameter.

In this report the two TNT based MCX-6002 and MCX-8001 compositions has been characterized with regard to critical diameter, detonation velocity and detonation pressure. MCX-6002 contains TNT as binder and the filler is NTO/RDX. Nominal content of MCX-6002 is NTO/TNT/RDX (51/34/15). This composition has content of NTO/RDX in the same range as the DNAN based US composition IMX-104 (53/31.7/15.3) (9, 10) and the DNAN based Chemring MCX-6100 composition (6, 7). MCX-8001 contains TNT as binder and the filler is NTO/HMX. Nominal content of MCX-8001 is NTO/TNT/HMX (52/36/11). This composition has content of NTO/HMX in the same range as the DNAN based US composition PAX-48 (53/35/12) (11) and the DNAN based Chemring MCX-8100 composition (8).

Critical diameter has been determined by use of cylindrical charges of different diameter and witness plates (12, 13). For MCX-6002 three conical charges were used to determine critical diameter. Detonation velocity was measured for cylindrical charges by use of 4-6 ionization pins (14, 15). Detonation pressure was determined by use of Plate Dent test (16, 17).

2 Experimentally

2.1 Detonation velocity and pressure

2.1.1 Casting

The test items for determination of detonation velocity and pressure were casted in Bjørkborn in Sweden by Nammo Liab with explosive produced by Chemring Nobel in Norway. Figure 2.1 shows a picture of the cylinder moulds after being filled with the two compositions to be characterized. The MCX-6002 composition was Lot DDP13A0003E and the MCX-8001 composition Lot DDP13A0004. The used moulds were measuring cylinders in polypropylene with a slightly conical form.

Figure 2.1 Filled moulds, 4 with MCX-6002 (left) and 4 with MCX-8001 (right) compositions after the melt had solidified.

2.1.2 MCX 6002

2.1.2.1 X-ray

Visual inspection of the filled moulds showed that quality of the top fillings was poor. We therefore decided to X-ray all moulds before releasing the fillings. The X-ray investigation was performed at Nammo Raufoss with a 320 kV apparatus. A picture of the X-ray film is given in Figure 2.2. The X-ray picture in Figure 2.2 shows that the quality of the casted fillings was poor. Not only in the top, but a least 10 cm down from the top, there were empty spaces. All fillings had areas with moderate or low density. However, we decided to use those parts of the charges that had moderate voids content and fewer defects for determining detonation velocity and detonation pressure.

The plastic cylinder was removed by cutting of the foot and then split the cylinder in the longitudinal direction. The parts with satisfactory density were cut in a lathe.

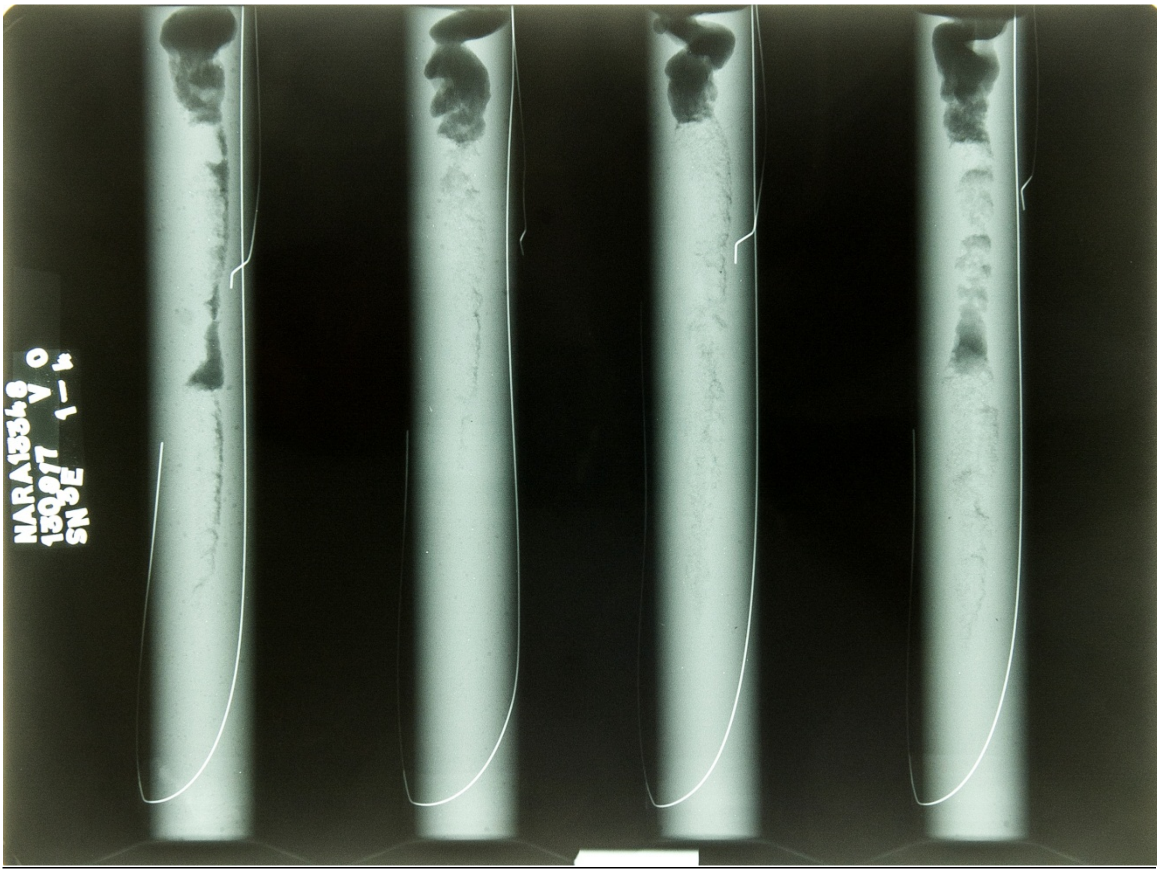

Figure 2.2 The figure shows the X-ray picture of the four tubes filled with MCX-6002 composition.

2.1.2.2 Density

Figure 2.3 shows the parts of each filling that had highest density. Weight and dimensions were measured for the five charges selected for producing test items for determination of detonation velocity.

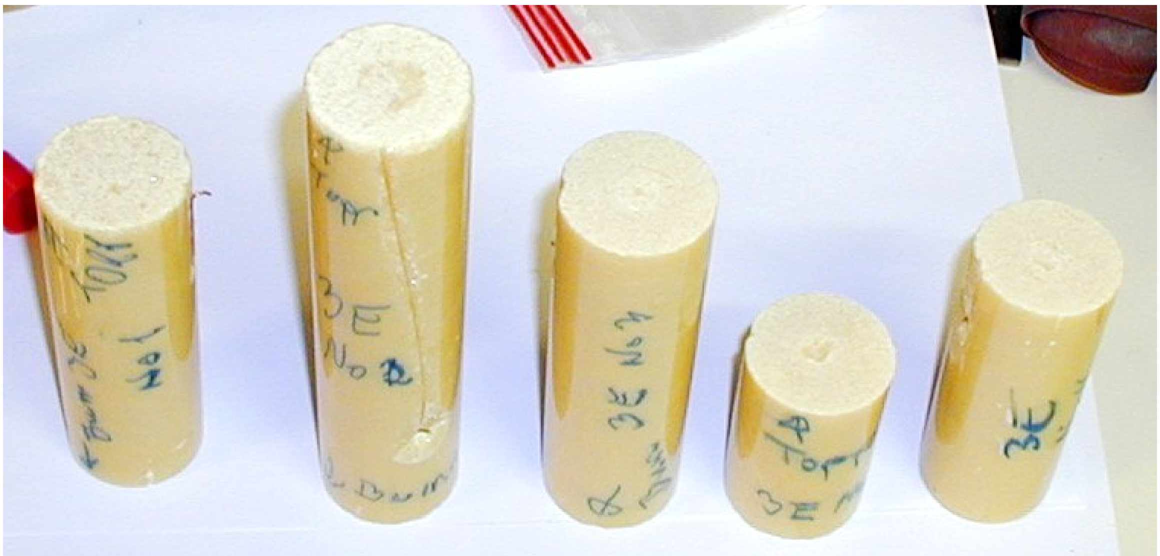

Figure 2.3 The picture shows the part of the charges that was selected to be tested.

Table 2.1 summarizes the properties of these charges. MCX-6002 with nominal content has a TMD of 1.7997 g/cm^3. The charges in Table 2.1 had a density from 97.3 %TMD for No 3 with 1.752 g/cm^3 to 99.6 %TMD for charge No 4 (1.796 g/cm^3).

Tube No	Weight (g)	Height (mm)	Diameter bottom (mm)	Diameter Top (mm)	Average Radius (cm)	Volume (cm^3)	Density (g/cm^3)
1	189.10	104.1	35.60	36.50	1.8025	106.2543	**1.780**
2	276.89	150.5	35.66	36.80	1.8115	155.1540	**1.785**
3	211.67	115.2	35.66	36.65	1.80775	118.2712	**1.790**
	108.36	57.67	36.76	37.15	1.84775	61.8566	**1.752**
4	160.79	88.20	35.60	36.30	1.79750	89.5275	**1.796**

Table 2.1 The table gives a summary of the dimensions and properties of the charges of MCX-6002 to be used for detonation velocity and pressure determination.

The charges shown in Figure 2.3 or given density in Table 2.1 have all satisfactory density. The exception is charge No 4 from left from the upper part of tube 3 with a density of 1.752 g/cm^3.

2.1.3 MCX-8001

2.1.3.1 X-ray

The MCX-8001 filling contain TNT/NTO/HMX (36/52/12). As for the MCX-6002 fillings, when we visually inspected the filled moulds, we saw empty space in top of the fillings and decided to take X-ray of them. Picture of the X-ray film is shown in Figure 2.4. The quality of the fillings is not significantly better than for MCX-6002 TNT/NTO/RDX (34/52/15). The number of large voids was significantly lower, but the size of the areas with reduced density was larger.

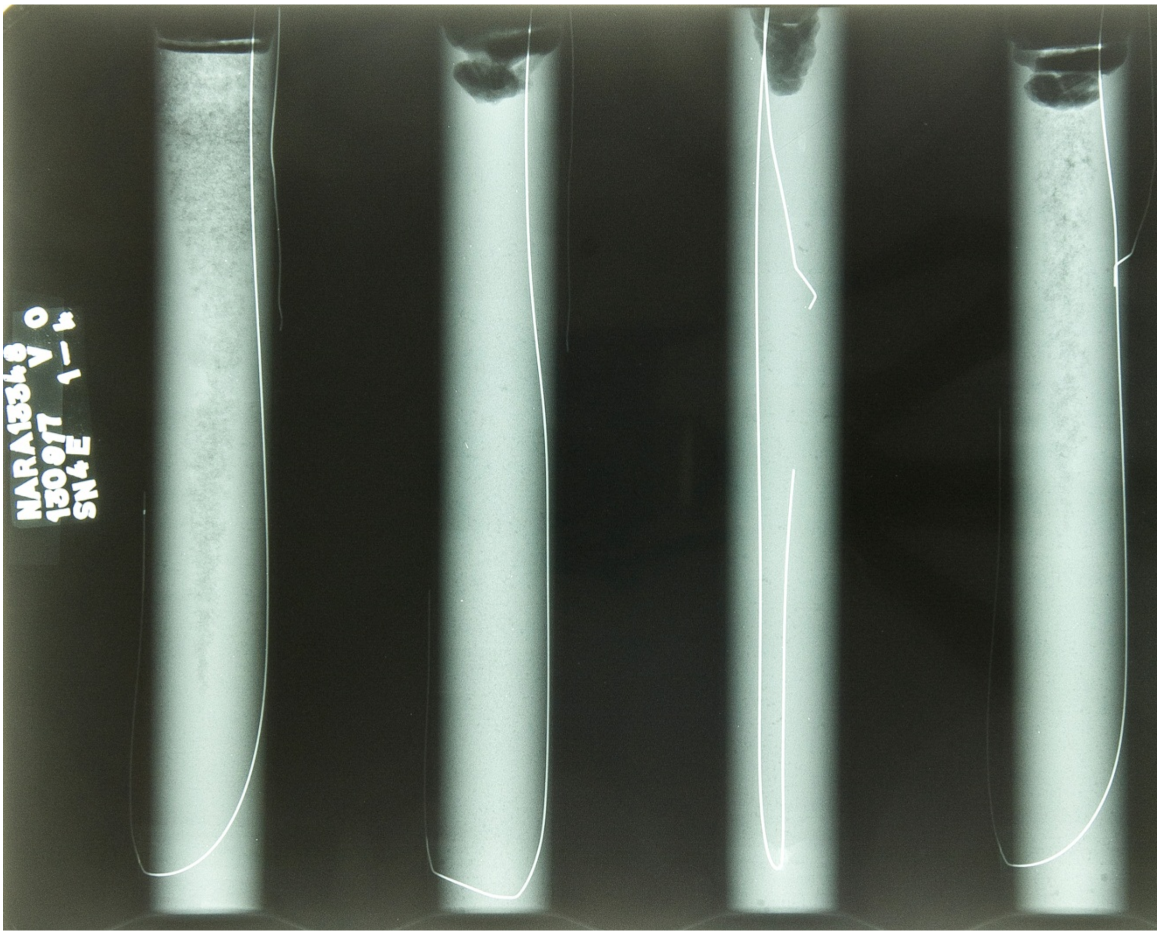

Figure 2.4 The picture shows the X-ray picture of the four tubes filled with MXC 8001 composition.

2.1.3.2 Density

To release the filling from the mould the plastic cylinder was removed by cutting of the foot and splitting the cylinder in the longitudinal direction. The parts of the fillings we wanted to test were cut in a lathe. Table 2.2 summarizes the properties of the charges selected for testing.

The filling with the most homogeneous cast is tube No 2. From this filling we cut a charge with a length of 223 mm. Tube No 1 and 4 had the poorest quality. Although tube No 3 looks relatively homogenous with some greyness and therefore the tube was cut into two pieces. From Table 2.2 one can see that the density of the upper piece (1.758 g/cm^3) is lower than in the lower part (1.778 g/cm^3). However, we decided to use both pieces in the determination of detonation velocity and detonation pressure.

As seen from Table 2.2 the obtained density for all pieces is below TMD (Theoretical Maximum Density) of 1.8087 g/cm^3. The deviation is acceptable. The piece from the middle of tube No 3 has a density of 97.2 % TMD as the lowest, while the charge from tube No 4 has the highest density of 98.9 % TMD. The charges of MCX-8001 selected for testing had lower density and percentage of TMD corresponding to MCX-6002 charges.

Figure 2.5 The figure shows pictures of the charges released to be tested.

Tube No	Weight (g)	Height (mm)	Diameter bottom (mm)	Diameter Top (mm)	Average Radius (cm)	Volume (cm^3)	Density (g/cm^3)
1	314.24	171.0	35.66	37.10	1.819	177.7507	**1.768**
2	416.73	223.0	35.65	37.45	1.8275	233.975	**1.781**
3	234.13	128.1	35.66	36.70	1.809	131.697	**1.778**
	180.92	94.55	36.90	37.55	1.86125	102.9013	**1.758**
4	254.59	138.5	35.60	36.75	1.80875	142.3498	**1.789**

Table 2.2 The table gives a summary of the dimensions and properties of the charges of MCX-8001 to be used for detonation velocity and pressure determination.

2.1.4 Detonation velocity measurements

To determine detonation velocity we used the method with ionization pins and setup for registration on the scope described in (14). The scope used to collect the results was a GWInstek GDS-3354, Digital Storage Oscilloscope, 350 MHz 5 GS/s adjusted to DC for the first 5 firings. For the last firing a GWInstek GDS-3352, Digital Storage Oscilloscope, 350 MHz 5 GS/s was used. A summary of the scope settings for the test firings are given in Table 2.3.

	Firing No 1	Firing No 2	Firing No 3	Firing No 4	Firing No 5	Firing No 6 Con.
Memory Length	25000	25000	25000	25000	25000	25000
Trigger Level	-2.28V	-2.28V	-2.28V	-2.28V	-2.28V	-2.64V
Source	CH1	CH1	CH1	CH1	CH1	CH1
Probe	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00
Vertical Units	V	V	V	V	V	V
Vertical Scale	2.000E+00	2.000E+00	2.000E+00	2.000E+00	2.000E+00	2.000E+00
Vertical Position	0.000E-00	0.000E-00	0.000E-00	0.000E-00	0.000E-00	4.000E+00
Horizontal Units	S	S	S	S	S	S
Horizontal Scale	5.000E-06	5.000E-06	5.000E-06	5.000E-06	5.000E-06	1.000E-05
Horizontal Position	2.000E-05	2.000E-05	2.000E-05	2.000E-05	2.000E-05	3.990E-05
Horizontal Mode	Main	Main	Main	Main	Main	Main
Sampling Period	2.000E-09	2.000E-09	2.000E-09	2.000E-09	2.000E-09	4.000E-09
Firmware	V1.09	V1.09	V1.09	V1.09	V1.09	V1.09
Time	08 Nov-13 13:09:17	08 Nov-13 13:21:58	08 Nov-13 13:35:35	08 Nov-13 13:47:07	08 Nov-13 14:11:19	14.03.2014 10:17
Mode	Detail	Detail	Detail	Detail	Detail	Detail
Waveform Data						

Table 2.3 The scope settings to collect the results for the firings.

2.2 Critical diameter

2.2.1 Cylindrical charges

In addition to charges for detonation velocity and detonation pressure determination, charges with different diameter for determination of critical diameter and mechanical properties were casted. The casting was performed by Nammo Liab in Karlskoga, Sweden. For MCX-6002 the Lot DDP13A0003E and for MCX-8001 the Lot DDP13A0004E was used for the casting. Figure 2.6 shows a picture of all these charges. The method used for determining critical diameter is described in reference (12). The length of the charges is twice the diameter.

The quality of all charges was investigated by X-ray performed at Nammo Raufoss. Figure 2.7 shows pictures of the X-ray films. Charges marked 3E contains composition MCX-6002, while 4E marked charges contains composition MCX-8001. For both compositions dark areas are observed indicating variation in density.

The charges were released from the plastic moulds with a longitudinal split produced by a bow file blade and opened with a screwdriver. All charges have a slightly conical shape, and some of them had in addition a slightly elliptical form. However, all charges were measured with regard to upper/lower diameter and height to determine the volume. Table 2.4 gives the obtained density for composition MCX-6002 of each selected charge to be tested. They have an average density of 1.749 g/cm^3 or 97.2% TMD.

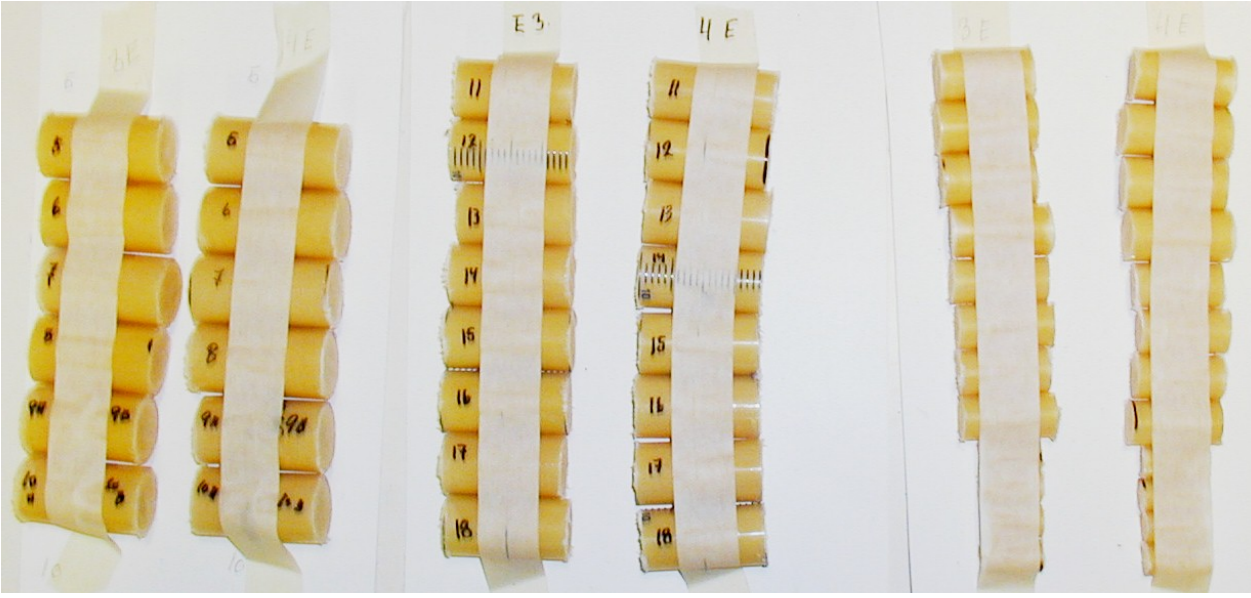

Figure 2.6 Pictures of the smaller charges casted for critical diameter and mechanical testing. Charges marked with 3E contain composition MCX-6002 and 4E contain composition MCX-8001.

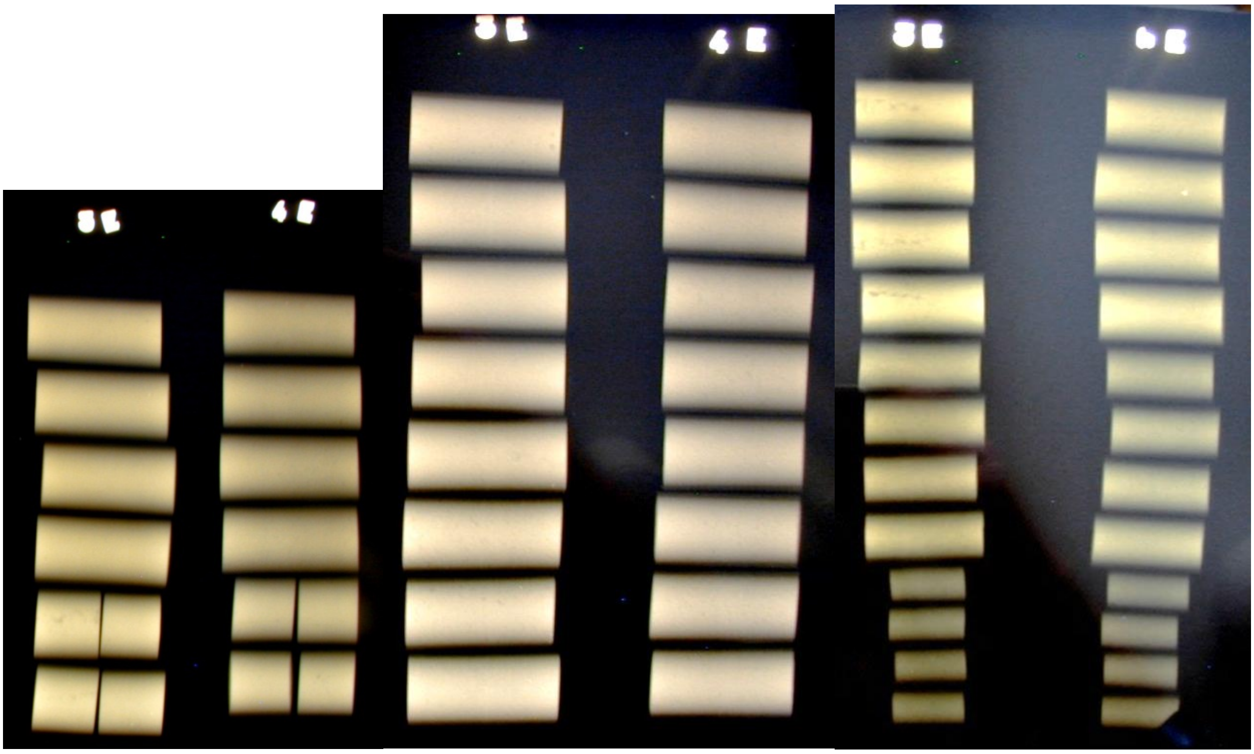

Figure 2.7 Pictures of X-ray films of the items in Figure 2.6. Charges marked with 3E contain composition MCX-6002 and 4E contain composition MCX-8001.

Test item No	Pellet No	Weight (g)	Height (mm)	Upper diameter (mm)	Lower Diameter (mm)	Average Radius (mm)	Volume (mm^3)	Density (g/cm^3)
		DDP13A0003E No 1 (RDX)						
1	1	4.0398	23.90	11.11	11.00	5.5275	2294.06	1.761
	2	11.3664	37.60	15.06	14.60	7.4150	6494.71	1.750
	3	20.9026	39.40	19.70	19.60	9.8250	11948.44	1.749
	4	33.7939	50.60	22.37	21.90	11.0675	19471.50	1.736
	5	48.2090	53.40	25.88	25.18	12.7650	27335.86	1.764
		Average						**1.752**
		DDP13A0003E No 2						
2	1	4.1735	25.01	11.21	11.04	5.5625	2431.10	1.717
	2	11.9201	39.50	15.07	14.64	7.4275	6845.93	1.741
	3	21.7984	41.12	19.74	19.55	9.8225	12463.70	1.749
	4	35.1475	52.35	22.36	21.88	11.0600	20117.63	1.747
	5	48.4822	53.70	25.89	25.24	12.7825	27564.86	1.759
		Average						**1.743**
		DDP13A0003E No 3						
3	1	4.2709	25.52	11.16	10.98	5.5350	2456.21	1.739
	2	12.1492	40.35	15.05	14.57	7.4050	6950.94	1.748
	3	22.0578	41.71	19.73	19.54	9.8175	12629.67	1.747
	4	32.3883	49.45	22.07	21.45	10.8800	18389.67	1.761
	5	48.1458	53.3	25.86	25.2	12.76500	27284.67	1.765
		Average						**1.752**

Table 2.4 Properties of cylindrical charges of MCX-6002 for determination of critical diameter.

Table 2.5 gives the properties of the charges casted with composition MCX-8001 selected for testing of the critical diameter. The density of these charges is slightly higher than for the MCX-6002 charges. They have an average density of 1.756 g/cm^3 or 97.1% TMD. TMD for MCX-8001 is 1.8087 g/cm^3.

Test item No	Pellet No	Weight (g)	Height (mm)	Upper diameter (mm)	Lower Diameter (mm)	Average Radius (mm)	Volume (mm^3)	Density (g/cm^3)
		DDP13A0004E No 1 (HMX)						
1	1	4.6032	26.90	11.20	11.04	5.560	2612.47	1.762
	2	11.5424	37.26	15.20	14.78	7.495	6575.61	1.755
	3	24.4353	45.47	19.76	19.60	9.840	13831.36	1.767
	4	33.8365	51.75	22.08	21.48	10.890	19280.40	1.755
	5	54.2749	59.20	26.15	25.45	12.900	30949.31	1.754
		Average						**1.759**
		DDP13A0004E No 2						
2	1	4.3528	25.55	11.25	11.00	5.5625	2483.60	1.753
	2	11.7574	37.70	15.25	14.88	7.5325	6720.00	1.750
	3	22.6914	42.35	19.79	19.66	9.8625	12941.28	1.753
	4	34.2107	50.60	22.37	21.92	11.0725	19489.10	1.755
	5	54.1404	59.55	26.08	25.38	12.8650	30963.58	1.749
		Average						**1.752**
		DDP13A0004E No 3						
3	1	4.4984	26.44	11.20	10.97	5.5425	2551.66	1.763
	2	11.6717	37.33	15.23	14.82	7.5125	6618.76	1.763
	3	23.4844	44.00	19.78	19.62	9.8500	13411.43	1.751
	4	33.9974	51.85	22.13	21.53	10.9150	19406.45	1.752
	5	51.5776	56.21	26.15	25.46	12.9025	29397.55	1.754
		Average						**1.757**

Table 2.5 Properties of casted cylindrical charges of MCX-8001for determination of critical diameter.

2.2.2 Conical charges MCX-6002

For determination of critical diameter for the MCX-6002 composition CH 6080/13 three conical charges were casted by Chemring Nobel.

2.2.2.1 Conical charge cast 7/14

The first charge to be tested was cast No 7/14. Figure 2.8 shows a picture of the charge after being released from the mould. The diameter of the charge at the top was 29.3 mm and at the

Figure 2.8 Picture of the MCX-6002 CH 6080/13 conical charge cast No 7/14.

bottom 5.4 mm. The charge had a weight of 116.03 g giving an overall density of 1.773 g/cm^3. Figure 2.9 shows the test item after the booster was added and the test item placed on the witness plate ready for testing.

Figure 2.9 Picture of the MCX-6002 CH 6080/13 conical charge cast No 7/14 after been assembled on the witness plate.

2.2.2.2 Conical charge cast 6/14

A picture of the received conical charge in the mould is shown in Figure 2.10. The charge had a diameter at the top of 27.3 mm and at the bottom of 3.4 mm. The weight was 94.12 g, which gives an overall density of 1.77 g/cm^3. Figure 3.11 shows the test item after modification of the top and the booster added.

Figure 2.10 Picture of the MCX-6002 CH 6080/13 cast No 6/14 in the mould.

Figure 2.11 Picture of the MCX-6002 CH 6080/13 cast No 6/14 after been assembled on the witness plate.

2.2.2.3 Conical charge cast 12/14

A picture of the conical charge after being released from the mould and booster added is shown in Figure 2.12. The cone had a diameter at the top of 30 mm and at the bottom of 4.0 mm. The weight was 119.12 g, which gave an overall density of 1.689 g/cm^3. Figure 3.13 shows the test item assembled on the witness plate ready for testing.

Figure 2.12 Picture of the MCX-6002 CH 6080/13 conical charge cast No 12/14 after been released from mould and added booster.

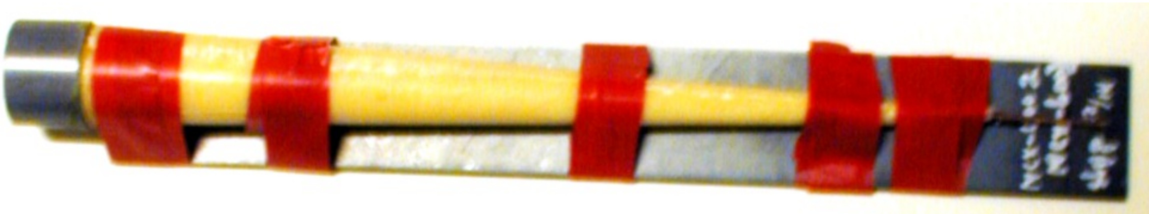

Figure 2.13 Picture of the MCX-6002 CH 6080/13 conical charge cast No 12/14 after been assembled on the witness plate.

2.3 Initiation

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

2.4 Gluing

For determination of both detonation velocity and critical diameter, charges had to be glued together to obtain the required test items. The first gluing was performed by using Araldite with 10 minutes curing time. This glue seems not to be compatible with our explosives. Figure 3.10 shows that the glue became red. We therefore changed the glue to Casco Kontaktlim.

2.5 Plate Dent test

Detonation pressure has been determined by use of Plate Dent test (16-17). 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 bolt had a height of 60 mm. Figure 2.14 shows how the Dent depth was measured with a micrometer screw, a steel ring and a steel ball.

Figure 2.14 Picture of the tool used to measure the Dent depth.

2.6 Theoretical calculations

Theoretical calculation has been performed by Cheetah 2.0 (18)

3 Results

3.1 Critical Diameter

Knowledge of the critical diameter is important in order to be able to initiate a composition in a satisfactory way. Several methods to perform the test exist, however, we selected cylindrical charges of different diameter with length 2xdiameter glued together to form a test item (12). We had available charges with 5 different diameters from 26 mm to 11 mm for Lot DDP13A0003E (MCX-6002) and Lot DDP13A0004E (MCX-8001). For both compositions these were glued together to 3 test items. For composition MCX-6002 CH 6080/13 we in addition casted 3 conical charges with diameter from 30 mm to 3 mm.

3.1.1 Cylindrical charges of MCX-6002

3.1.1.1 Shot No 1

The first test was performed with test item No 1 in Table 2.4 glued together into a test item as shown in Figure 3.1 and the left picture. The test item contained 5 cylindrical charges with different diameters. The right picture in Figure 3.1 shows the witness plate after the firing. The central picture shows the setup before firing.

Figure 3.1 Different pictures of the test item used to determine critical diameter: from left after being glued together, test setup for firing and right the witness plate after firing.

We interpreted the witness plate as a detonation took place through the full length of the charge, and that the critical diameter was 11 mm or less.

3.1.1.2 Shot No 2

The second test was performed with the test item No 2 in Table 2.4. It was glued together into a test item as shown in Figure 3.2 at the left picture. The right picture in Figure 3.2 shows the witness plate after firing. The central pictures show the assembled test item on the witness plate and the setup for firing.

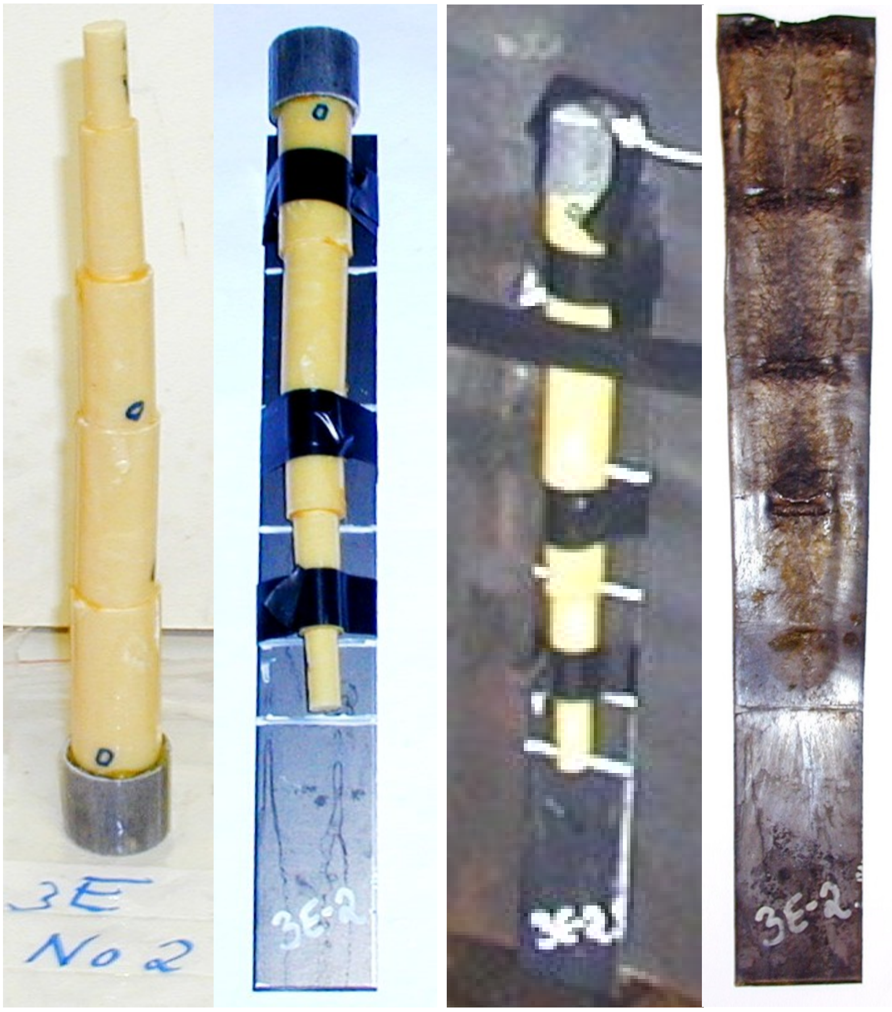

Figure 3.2 Different pictures: from left the test item after being glued together, next after the test item been assembled on the witness plate, setup for firing and to the right the witness plate after firing.

Inspection of the witness plate shows that a detonation took place through the full length of the charge, and that the critical diameter is 11 mm or less.

3.1.1.3 Shot No 3

The third test was performed with test item No 3 in Table 2.4. It was glued together into a test item as shown in Figure 3.3 at the left picture. The right picture in Figure 3.3 shows the witness plate after the firing. The central pictures show the assembled test item on the witness plate and the setup for firing.

Figure 3.3 Different pictures: from left the test item after being glued together, next after the test item had been assembled on the witness plate, setup for firing and to the right the witness plate after firing.

Inspection of the witness plate shows that a detonation took place through the full length of the charge, and that the critical diameter is 11 mm or less.

3.1.2 Conical charges of MCX-6002

3.1.2.1 Cast 7/14

The above testing of critical diameter for MCX-6002 lot DDP13A0003E (MCX-6002) did not result in a specific value, since the detonation continued through the charge. Therefore, three conical charges with MCX-6002 CH 6080/13 were casted. The first test item was cast No 7/14 (according to

Chemring marked with the Number 2). Figure 3.4 shows the test item after the added booster and the charge was assembled on the witness plate. In addition the figure 3.4 gives pictures of the test setup and of the witness plate after firing.

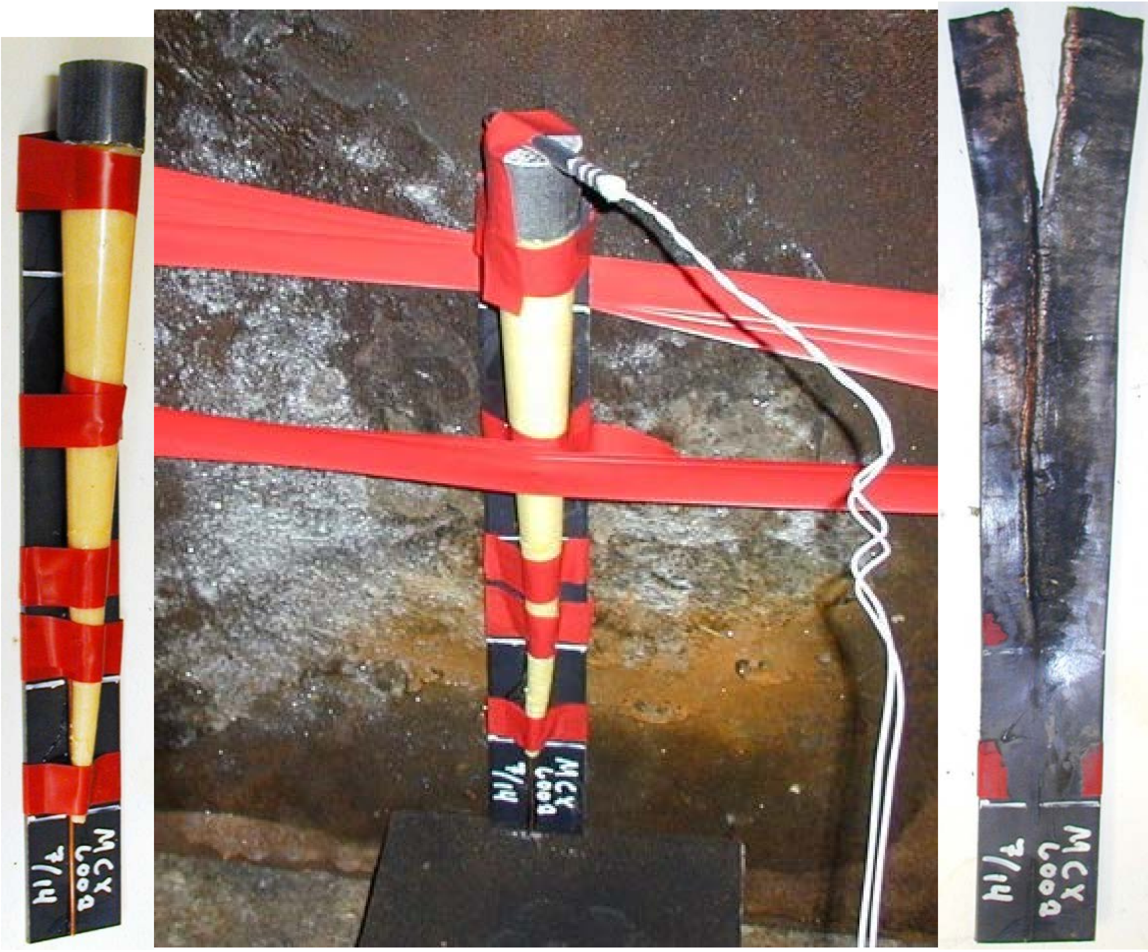

Figure 3.4 The figure shows from left; the test item after assembled, test setup for firing and to the right the witness plate.

Inspection of the witness plate gave a critical diameter of 10.0 mm. This is a result slightly below the obtained results for the cylindrical charges.

3.1.3 Cast 6/14

The second tested cone was conical charge cast No 6/14. Properties are given in section 2.2.2.2. Figure 3.5 shows pictures of the test setup and the witness plate after firing. For this firing the critical diameter was measured to 9.8 mm.

Figure 3.5 Setup and the witness plate for testing of conical charge cast 6/14 with MCX-6002 CH 6080/13 composition.

3.1.3.1 Cast 12/14

The last tested conical charge with MCX-6002 CH 6080/14 was cast No 12/14. Chapter 2.2.2.3 gives the properties of the conical charge. This conical charge was equipped with four ionization pins to simultaneously measure the detonation velocity as function of the diameter. Pins were positioned at a critical diameter of 27 mm, 18 mm, 12 mm and finally at 9 mm. This gave a distance between pin No 1 and pin No 2 of 90 mm, between pin No 2 and pin No 3 of 60 mm and finally between pin No 3 and pin No 4 of 30 mm. Figure 3.6 shows the setup and the witness plate for this firing.

Figure 3.6 The figure shows test setup and witness plate for firing of conical charge cast 12/14 containing MCX-6002 CH 6080/13 composition.

Inspection of the witness plate gave a critical diameter of 10.3 mm. The result from the instrumentation is given in section 3.2.1.3.

3.1.3.2 Comparing the conical charge results

Figure 3.7 shows pictures of the three witness plates for the firings with conical charges of the MCX-6002 CH 6080/13 composition. Table 3.1 summarizes the results showing an average critical diameter of 10 mm. This result gives a slightly smaller critical diameter than obtained with the cylindrical charges (less than 11 mm). For both test methods an overdrive may occur.

Firing No	**CH 6080/13 cast**	**Density (g/cm^3)**	**Critical Diameter (mm)**
1	7/14	1.773	10.0
2	6/14	1.77	9.8
3	12/14	1.689	10.3
	Average firing 1-3		**10**

Table 3.1 Summary of the test results for determination of critical diameter for charges of MCX-6002 CH 6080/13 composition.

Figure 3.7 The figure shows two pictures of the witness plates for the three firing with conical charges containing MCX-6002 CH 6080/13 compositions.

3.1.4 Cylindrical charges of MCX-8001

3.1.4.1 Shot No 1

The first test was performed with the test item No 1 in Table 2.5. I t was glued together into a test item as shown in Figure 3.8 at the left picture. The right picture in Figure 3.8 shows the witness plate after the firing. The central pictures show the test item assembled on the witness plate and the setup for firing.

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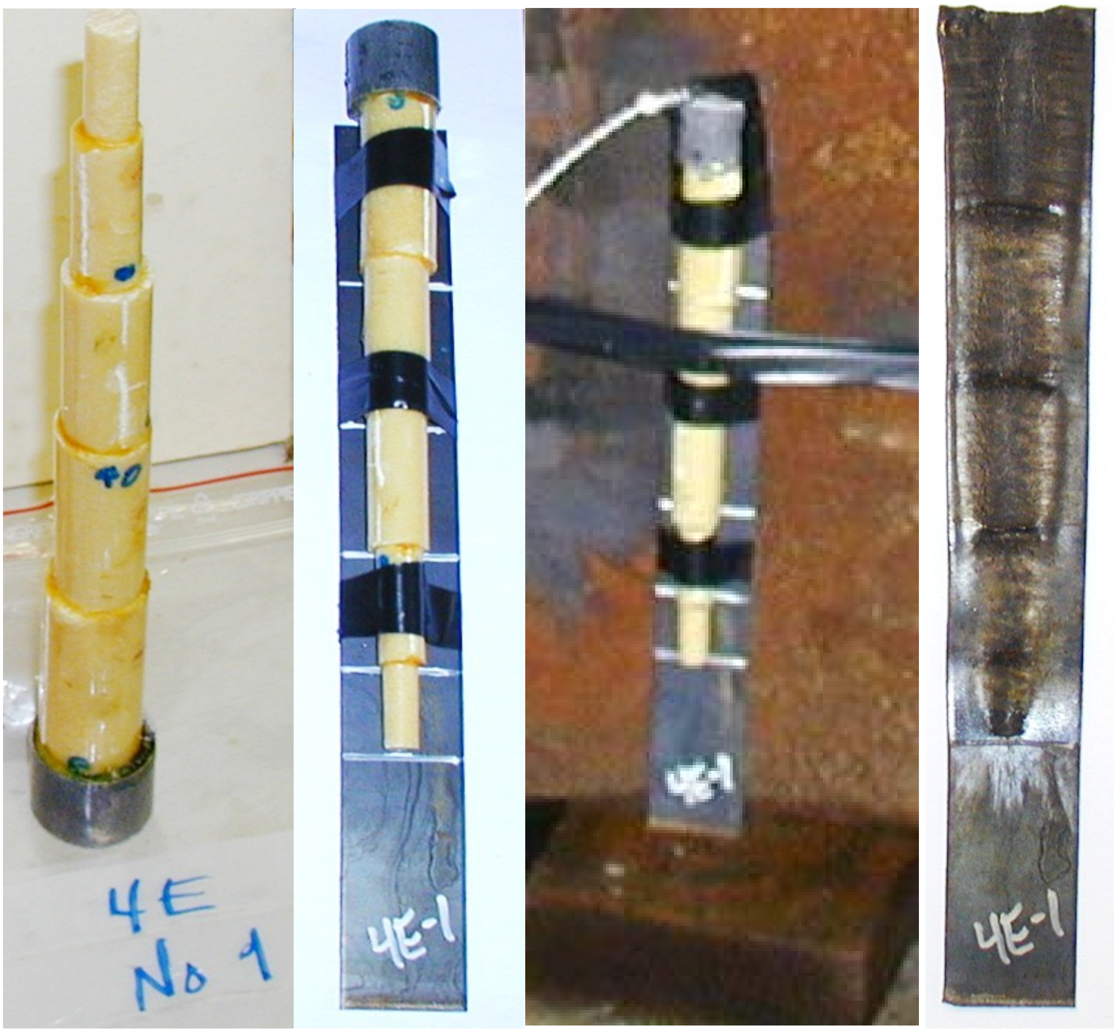

Figure 3.8 Different pictures: from left the test item after being glued together, next after the test item been assembled on the witness plate, setup for firing and to the right the witness plate after firing.

Interpretation of the result gave verification of detonation through the full length of the charge. This gives a critical diameter of less than 11 mm.

3.1.4.2 Shot No 2

The second test was performed with the test item No 2 in Table 2.5. This sample was glued together into the test item shown in Figure 3.9 at the left picture. The right picture in Figure 3.9 shows the witness plate after the firing. The central pictures show the test item assembled on the witness plate and the setup for firing.

Figure 3.9 Different pictures: from left the test item after being glued together, next after the test item been assembled on the witness plate, setup for firing and to the right the witness plate after firing.

Interpretation of the result showed detonation through the full length of the charge. This gives a critical diameter of less than 11 mm.

3.1.4.3 Shot No 3

The third test was performed with test item No 3 in Table 2.5. This was glued together into the test item shown in Figure 3.10 at the left picture. The right picture in Figure 3.10 shows the witness plate after the firing. The central pictures show the test item assembled on the witness plate and the setup for firing.

Figure 3.10 Different pictures: from left the test item after being glued together, next after the test item been assembled on the witness plate, setup for firing and to the right the witness plate after firing.

Interpretation of the result showed detonation through the full length of the charge. This gives a critical diameter of less than 11 mm.

3.2 Detonation Velocity

3.2.1 MCX-6002

From the four cylindrical charges in Figure 2.1, we cut 5 pieces with satisfactory quality with respect to pores and low density area. Table 2.1 gives the average density for these 5 charges. These 5 charges were glued together into two test items having a length to positioning 4 ionization pins to determine the detonation velocity.

3.2.1.1 Shot No 2

The first test item of MCX-6002 lot DDP13A0003E (MCX-6002) contained parts from tube 2 and tube 3. The piece from tube 3 was taken as bottom of the test item and in contact with the Dent witness plate. Figure 3.11 shows where the ionization pins were positioned. Pin No 1 and Pin No 2 in the piece from tube 2 had an average density of $\rho = 1.785$ g/cm^3. Pin No 3 and pin No 4 was positioned in the piece from tube 3 having a density of $\rho = 1.7897\ g/cm^3$. For both pieces the bottom from the casting was farthest from the initiation end. All 4 ionization pins gave registration as shown in Figure 3.12.

Figure 3.11 Left picture shows the charge after the ionization pins had been positioned. Right picture shows the charge setup for firing.

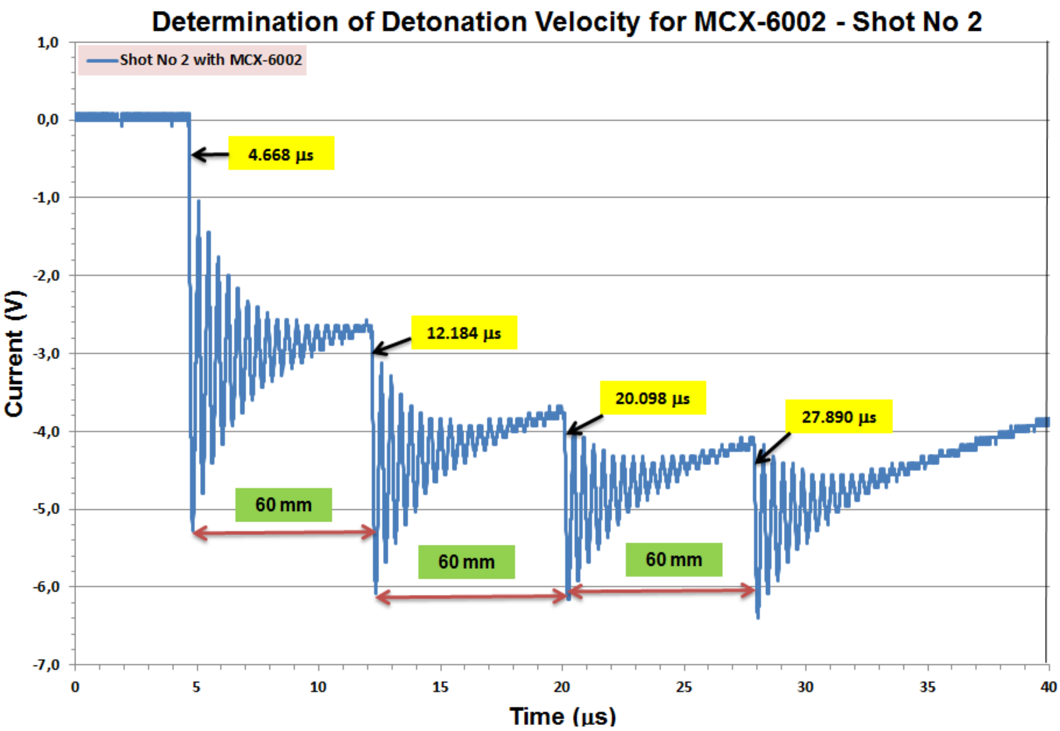

Figure 3.12 The figure shows the arrival time of the detonation front for each pin and the distance between pins.

Obtained detonation velocities are summarized in Table 3.2 and shows that the velocity for the piece from tube 2 is 7983 m/s and for the part from tube 3 it is 7700 m/s. The velocity between the two tubes (pin No 2 and pin No 3) is lower, 7582 m/s. On average the detonation velocity is measured to 7751 m/s, slightly below the theoretical velocity calculated by Cheetah at TMD.

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 MCX-6002 Lot DDP13A0003E			
1	4.668			
2	12.184	7.516	60	**7983**
3	20.098	7.914	60	7582
4	27.890	7.792	60	**7700**
1-4		23.222	180	**7751**

Table 3.2 A summary of the results from the determination of the detonation velocity for MCX-6002 test No 1.

3.2.1.2 Shot No 3

The second tested item with MCX-6002 composition lot DDP13A0003E (MCX-6002) was shot No 3. It was made from as bottom a piece from tube 4, in the middle a piece from tube No 1 and at the initiation end a piece from tube No 3. 4 ionization pins, pin No 1 and No 2 positioned in the piece from tube 1 with density ρ = 1.7797 g/cm^3 and pin No 3 and No 4 positioned in the piece from tube 4 having density ρ = 1.7960 g/cm^3. Figure 3.13 shows pictures of the test item with and without ionization pins and a picture of the setup for firing. Figure 3.14 shows the registrations obtained at the scope. In addition the distances between the ionization pins are given.

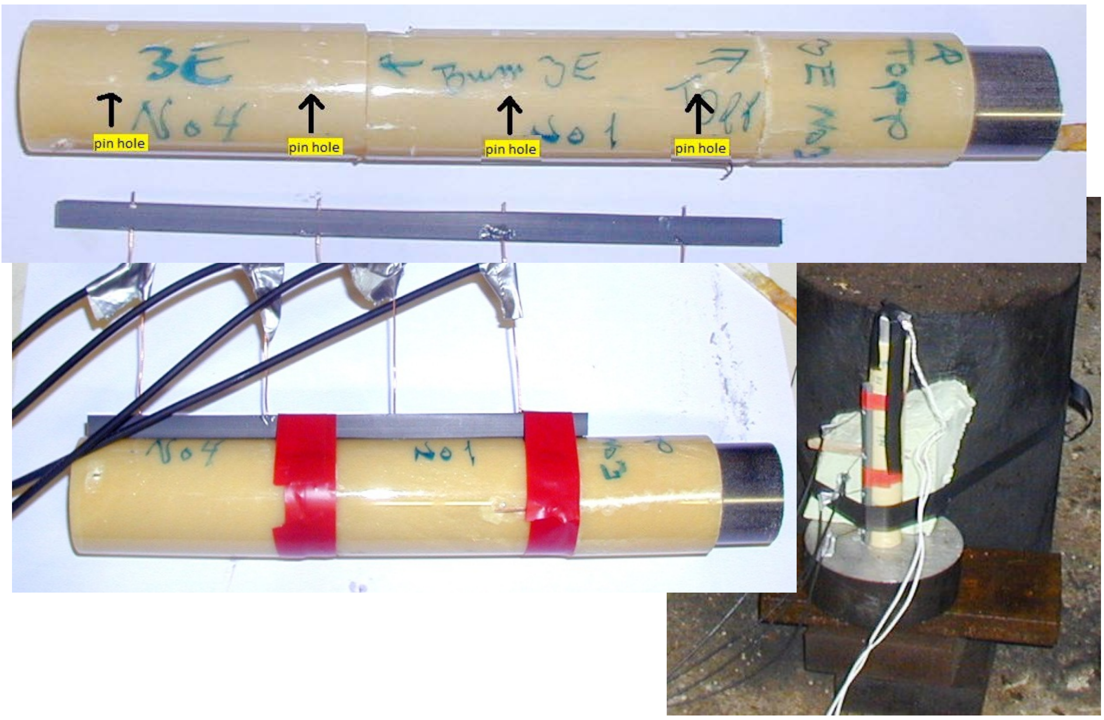

Figure 3.13 The first picture shows where the ionization pins were positioned. The second picture shows the charge after the pins was set in and the right picture shows the setup for testing.

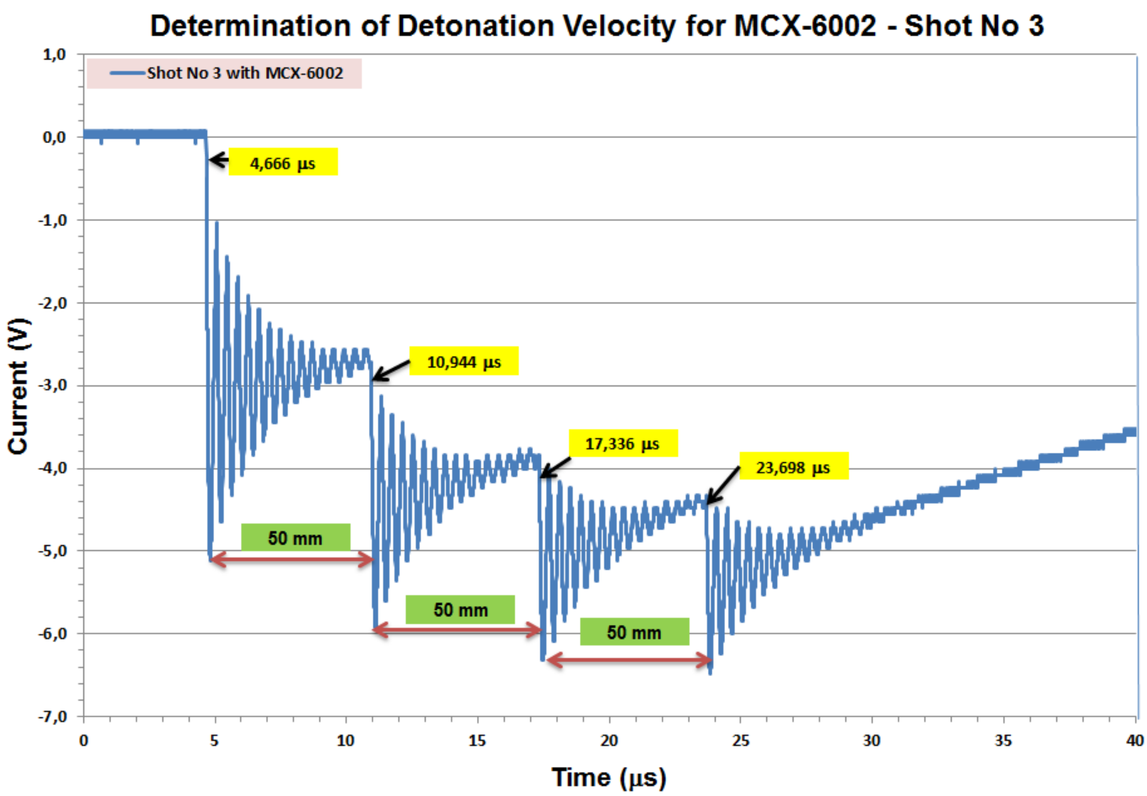

Figure 3.14 The figure shows the arrival time of the detonation front for each pin and the distance between pins.

The detonation velocities are summarized in Table 3.3 showing that the velocity for the piece from tube 1 is 7964 m/s and for the piece from tube 4 is 7859 m/s. The velocity between the two pieces (pin No 2 and pin No 3) is slightly lower, 7822 m/s. On average the detonation velocity is measured to 7881 m/s, or 130 m/s higher than for test No 1.

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 MCX-6002 Lot DDP13A0003E			
1	4.666			
2	10. 944	6.276	50	**7964**
3	17.336	6.394	50	7822
4	23.698	6.362	50	**7859**
1-4		19.032	150	**7881**

Table 3.3 A summary of the results from the determination of the detonation velocity for MCX-6002 test No 2.

3.2.1.3 Conical charge with MCX-6002

Cast 12/14 was equipped with 4 ionization pins for determination of detonation velocity as function of charge diameter. The position of the pins was selected to have one pin just before and one pin just after the expected failure diameter at a charge diameter (CD) of 12 mm and at 9 mm. The last two pins were positioned at the top (CD 27 mm) and in the middle (CD 18 mm) of the charge. Figure 3.15 shows the positions of all ionization pins.

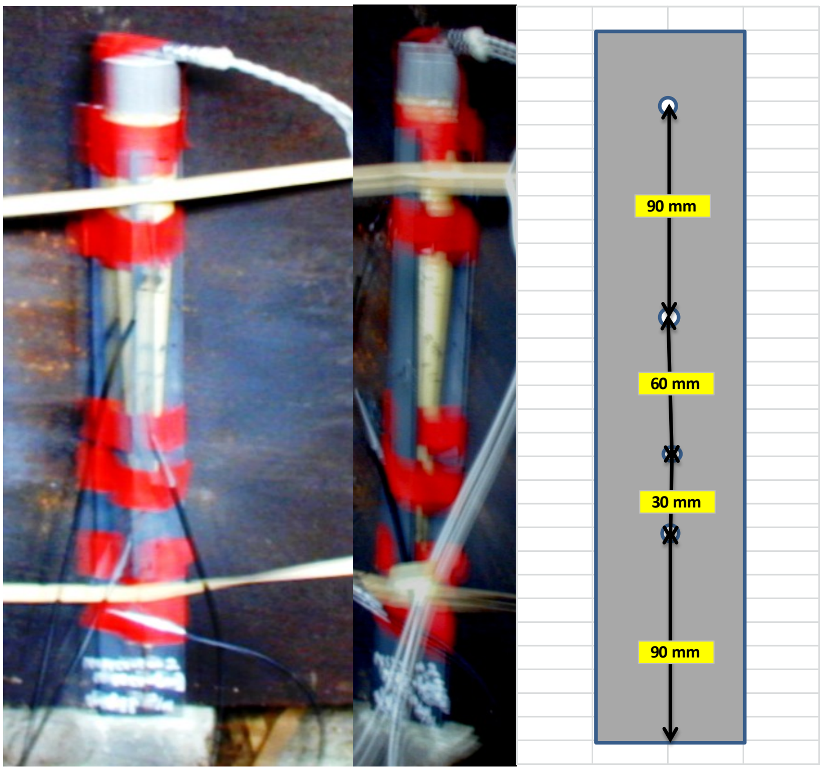

Figure 3.15 The figure shows diffused pictures of the test setup and a drawing with the positions of the ionization pins.

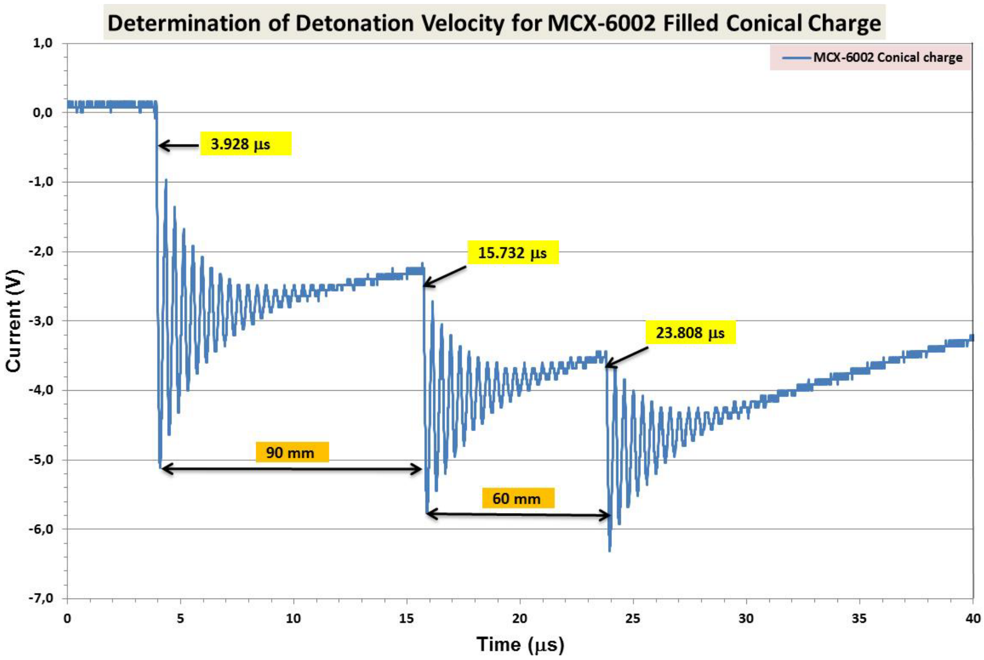

Figure 3.16 The figure shows the arrival time of the detonation front for each pin and the distance between pins for the conical firing of MCX-6002 CH 6080/13.

Figure 3.16 shows registration for 3 of the 4 ionisation pins. The last ionization pin with registration was positioned at a critical diameter of 12 mm. The pin that failed was positioned at charge diameter of 9 mm. The witness plate gives a critical diameter of 10 mm and confirms the registration obtained with the ionization pins. The obtained velocity between pin No 1 and pin No 2 of 7632 m/s is slightly lower than for the cylindrical charges with diameter 36±1 mm. For the part of the cone having diameter between 18 mm and 12 mm, the average detonation velocity was measured to 7429 m/s.

The tested cone had significantly lower average density (1.689 g/cm^3) than the cylindrical charges. In addition smaller charge diameter may have influenced on the detonation velocity. That pin No 4 gave no registration confirms a critical diameter larger than 9 mm but less than 12 mm.

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 containing MCX-6002 CH 6080/13 cast 12/14			
1	3.94			
2	15.732	11.792	90	7632
3	23.808	8.076	60	7429
4	No registration		30	
1-3		19.868	150	**7550**

Table 3.4 A summary of the results from the determination of the detonation velocity for MCX 6002 CH 6080/13 conical charge cast 12/14.

3.2.1.4 Summary of detonation velocity for MCX-6002

Table 3.5 summarizes the measured detonation velocities for MCX-6002 Lot DDP13A0003E and CH 6080/13. For the 4 different charges (bold black number) the average velocity is 7877±130 m/s. By including the transitions between the charges gives an average of 7818±155 m/s.

The lower detonation velocity for the conical charge can be due to lower density and lower charge diameter or a combination of both. The fact that the velocity is as high as 7429 m/s at a charge diameter of 12 mm indicates that the overdrive of the reaction is moderate and that the critical diameter obtained by use of witness plate is representative for MCX-6200 composition.

Firing No	Cast No	Charge diameter (mm)	Average Charge density (g/cm^3)	Between pin No	Measuring distance (mm)	Detonation velocity (m/s)
2	**2**	35.66-36.80	1.785	1-2	60	**7983**
				2-3	60	7582
	3	35.66-36.65	1.790	3-4	60	**7700**
				1-4	180	**7751**
3	**1**	36.60-36.50	1.780	1-2	50	**7964**
				2-3	50	7822
	4	35.60-36.30	1.796	3-4	50	**7859**
				1-4	150	**7881**
6	**12/14 (conical charge)**	27	1.689	1-2	90	7632
		18		2-3	60	7429
		12		3-4	30	-
		9		1-3	150	**7550**

Table 3.5 The table summarizes the obtained detonation velocities for MCX-6002.

3.2.2 MCX 8001

From the four tubes casted with Lot DDP13A0004E, 5 pieces were cut off with satisfactory quality with respect to pores density. Table 2.2 gives the dimensions and density for the pieces. From tube 2 a charge with a length of 223 mm was obtained, long enough to be tested without extension by a piece from one of the other tubes. The remaining 4 pieces in Table 2.2 were glued together to two test items. All pieces had sufficient length to position 2 ionization pins. All 3 test items were fitted with 4 ionization pins.

3.2.2.1 Shot No 1

The first tested item was MCX-8001 composition Lot DDP13A0004E, called shot No 1. The test item was glued together with the bottom from a piece of tube 4 and at the initiation ends a piece from tube No 3. We used 4 ionization pins: pin No 1 and pin No 2 positioned in the piece from tube 3 with density $\rho = 1.778$ g/cm^3 and pin No 3 and pin No 4 in the piece from tube 4 having density $\rho = 1.789$ g/cm^3. Figure 3.17 shows a picture of how the ionization pins were positioned. The distance between pin No 1 and pin No 2 was 60 mm, between pin No 2 and pin No3 60 mm and finally between pin No 3 and pin No 4 90 mm. Figure 3.18 shows the test setup.

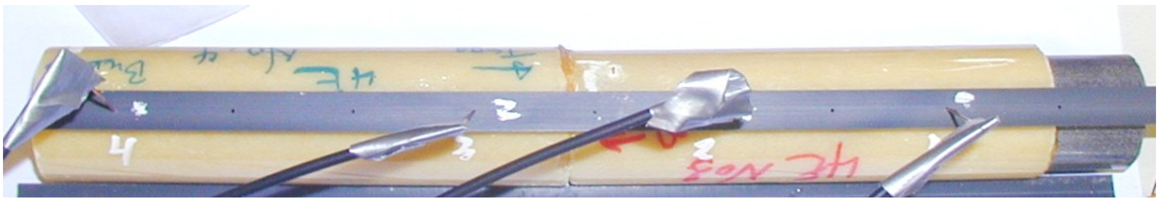

Figure 3.17 Picture of the test item with the ionization pins.

Figure 3.18 Test setup for the first firing with MCX-8001 Lot DDP13A0004E.

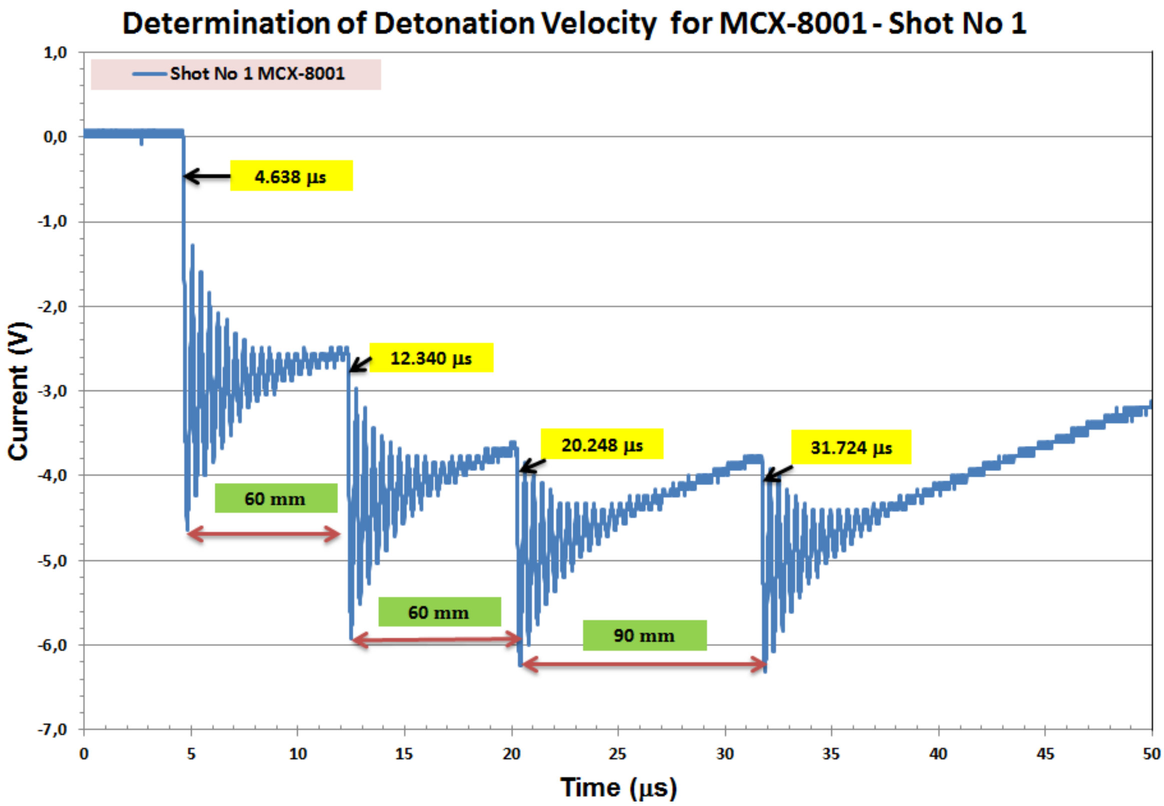

Figure 3.19 The figure shows the arrival time of the detonation front for each pin and the distances between the pins for shot No 1 containing MCX-8001.

Obtained detonation velocities are summarized in Table 3.6, showing velocities for the piece from tube 3 at 7790 m/s and for the part from tube 4 at 7842 m/s. The velocity between the two pieces (pin No 2 and pin No 3) is lower, 7587 m/s. The overall detonation velocity between pin No 1 and pin No 4 is 7753 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 MCX-8001 Lot DDP13A0004E			
1	4.638			
2	12. 340	7.702	60	7790
3	20.248	7.908	60	7587
4	31.724	11.476	90	7842
1-4		27.086	210	**7753**

Table 3.6 A summary of the results from the determination of the detonation velocity for MCX 8001 test No 1.

3.2.2.2 Shot No 4

The second tested item with MCX 8001 composition was shot No 4. It contained tube 2 without lengthening pieces from other tubes. This charge had an average density of ρ = 1.7811 g/cm^3. To determine detonation velocity 4 ionization pins were positioned with No 1 closest to the initiation end. Figure 3.20 shows pictures of the charge, the test setup and how the ionization pins were positioned in addition to the scope with obtained registration after firing.

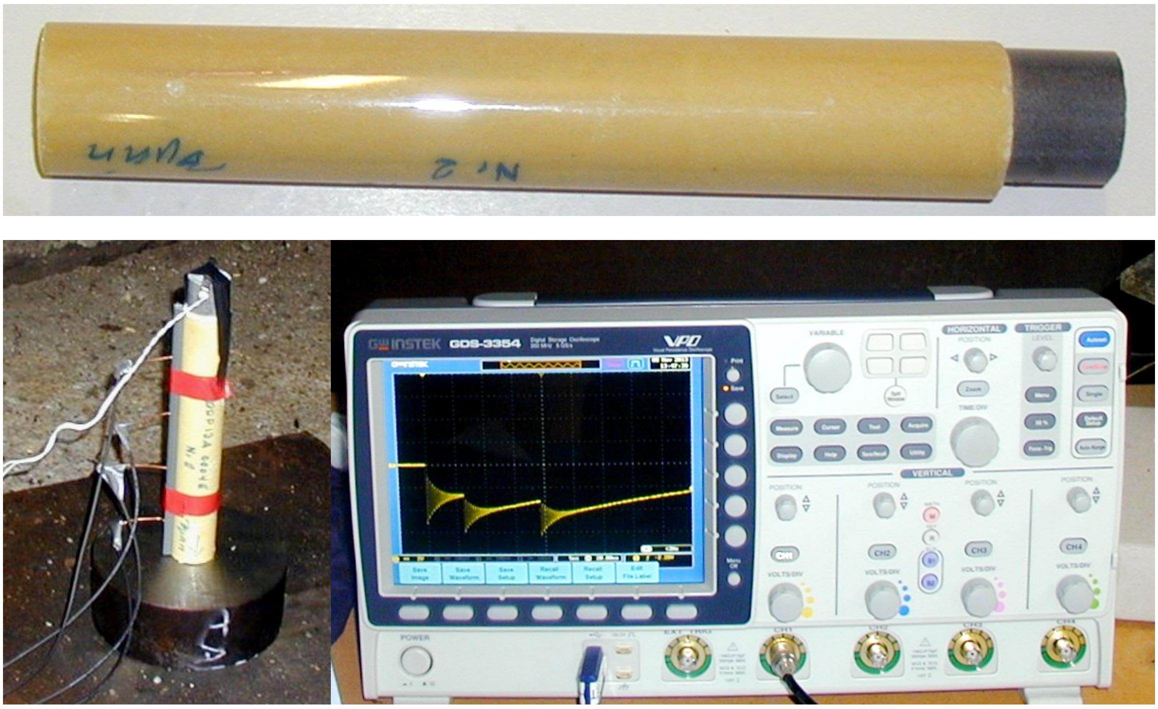

Figure 3.20 The first picture is of the test item; second left test setup for firing and on right a picture of the used scope with the obtained registration.

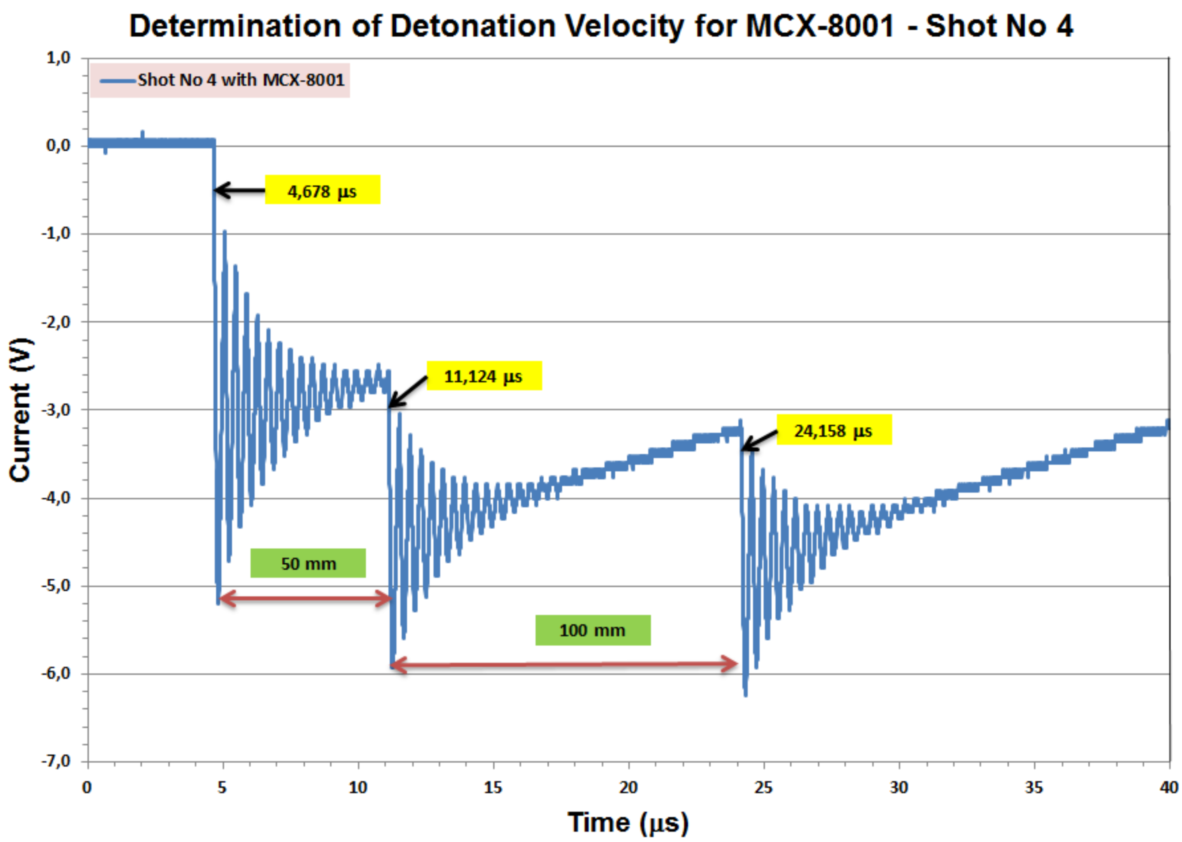

Figure 3.21 The figure shows the arrival time of the detonation front for each pin and the distance between pins.

As shown both in Figures 3.20 and 3.21 we did not obtain registration for ionization pin No 3. However, for pin No 1, pin No 2 and pin No 4 we obtained registrations. As Table 3.7 shows we obtain an average detonation velocity of 7700 m/s between pin No 1 and pin No 4. This is a slightly lower detonation velocity than for the first shot with MCX-8001 having an overall velocity of 7753 m/s. It looks like the detonation velocity for test item 2 is highest close to the initiation end and lowest at the bottom. However, the differences in velocity are small and the number of pointes too few in order to draw a qualified conclusion.

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 MCX-8001 Lot DDP13A0004E			
1	4.678			
2	11. 124	6.446	50	7757
3	No registration			
4	24.158	13.034	100	7672
1-4		19.480	150	**7700**

Table 3.7 A summary of the results from the determination of the detonation velocity for MCX-8001 test No 2.

3.2.2.3 Shot No 5

The third tested item with MCX-8001 composition was shot No 5. The test item was made from a piece from tube 3 as the bottom and at the initiation end of a piece from tube No 1.

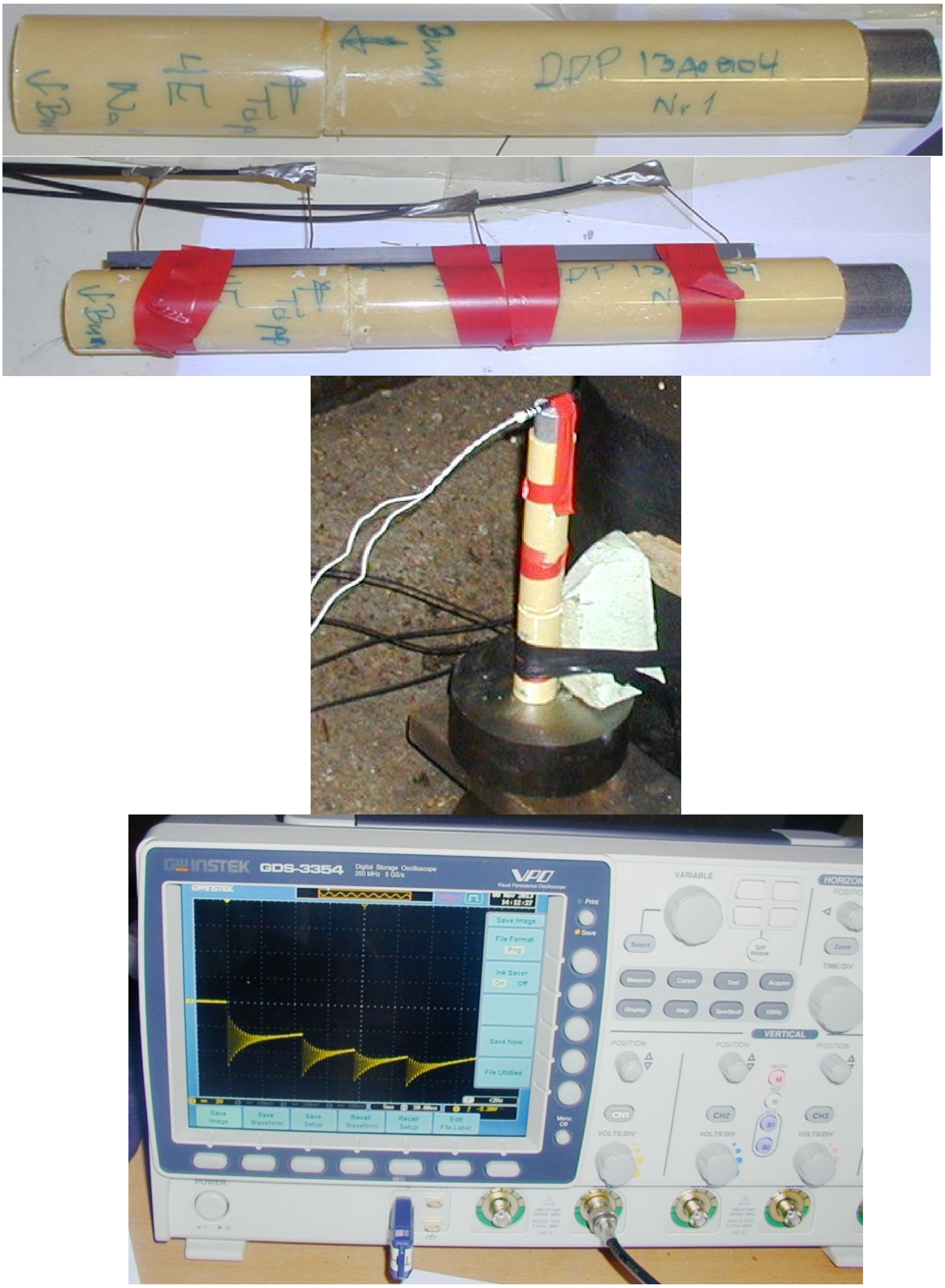

Figure 3.22 The two first pictures show the test item without and with the ionization pins follow by the test setup and the scope with the obtained registration.at the bottom

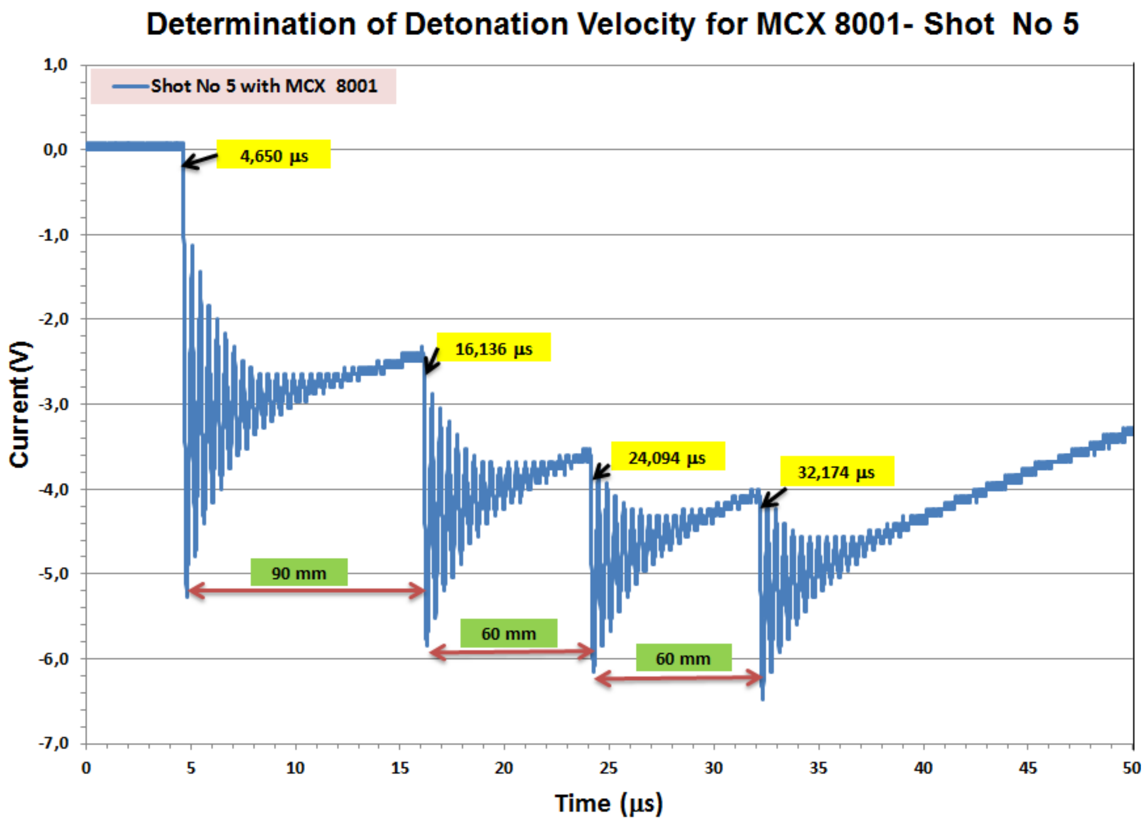

Figure 3.23 The figure shows the arrival time of the detonation front for each pin and the distance between pins.

We used 4 ionization pins, pin No 1 and pin No 2 in the piece from tube 1 with density ρ = 1.768 g/cm^3 and pin No 3 and pin No 4 in the piece from tube 3 having a density of ρ = 1.758 g/cm^3. Figure 3.22 shows pictures of test item, setup and scope registration after firing. All ionization pins gave registration.

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 5 MCX-8001 Lot DDP13A0004E			
1	4.650			
2	16. 136	11.486	90	7836
3	24.094	7.958	60	7540
4	32.174	8.080	60	7426
1-4		27.524	210	**7630**

Table 3.8 A summary of the results from the determination of the detonation velocity for MCX-8001 test No 3.

Detonation velocities are summarized in Table 3.8 showing a detonation velocity in the piece from tube 1 as 7836 m/s and in the piece from tube 3 as 7426 m/s. The velocity between the two pieces (pin

No 2 and pin No 3) is 7540 m/s. The overall detonation velocity is measured to 7630 m/s. These results do not reflect the differences in density between tube 1 with density $\rho = 1.768$ g/cm^3 and tube 3 having a density of $\rho = 1.758$ g/cm^3.

3.2.2.4 Summary of detonation velocity MCX-8001

Table 3.9 summarizes the measured detonation velocities for MCX-8001 Lot DDP13A0004E. The average velocity in single pieces is 7719 $\pm$ 173 m/s. Excluding the piece from tube 3 with low detonation velocity, the average was 7792$\pm$66 m/s. Including transition measurements gave an average velocity of 7681$\pm$152 m/s.

Firing No	Cast No	Charge diameter (mm)	Charge density (g/cm3)	Between pin No	Measuring distance (mm)	Detonation velocity (m/s)
1	3	36.90-37.55	1.778	1-2	60	**7790**
				2-3	60	7587
	4	35.60-36.55	1.786	3-4	90	**7842**
				1-4	210	**7753**
4	2	35.65-37.45	1.781	1-2	50	7757
				2-3	50	
				2-4	100	7672
				1-4	200	**7700**
5	1	35.66-37.10	1.768	1-2	90	**7836**
				2-3	60	7540
	3	35.66-36.70	1.758	3-4	60	**7426**
				1-4	210	**7630**

Table 3.9 The table summarizes the results for determination of detonation velocities of MCX-8001.

3.3 Plate Dent Test

3.3.1 MCX-6002

When determining the detonation velocity we also determined detonation pressure by use of the Plate Dent test. The Dent plates had a thickness of 60 mm which is at the limit for these explosive compositions. All witness plates with a Dent depth of 6 mm or more showed a slightly bump on the backside. Appendix A gives the certificate of the used ST-52 bolt.

Figure 3.24 shows both test setup and the Dent plates after firing for the two performed tests with MCX-6002 composition Lot DDP13A0004E. The obtained results for both tests are close to the expected result from theoretical calculation with Cheetah of 260 kbar at TMD. Table 3.10 gives the results.

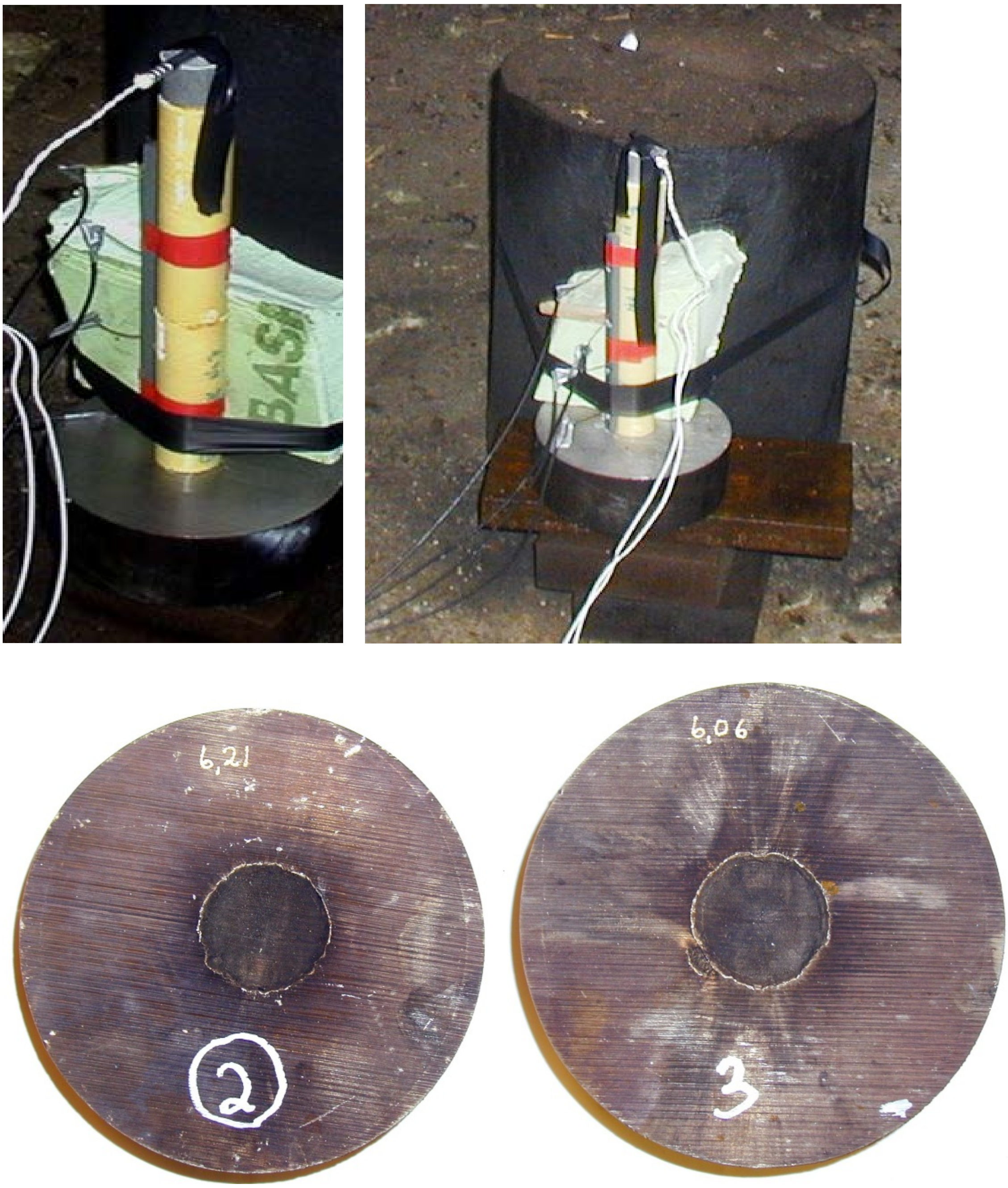

Figure 3.24 The Figure shows the setup and the Dent plates after firing for the two tested charges containing the MCX 6002 composition.

Shot No	From tube No	Charge diameter (mm)	Density (g/cm^3)	Dent Depth (mm)	Detonation pressure (kbar)
2	2 +3	35.66	1.790	6.21	**250.8**
3	4+1+3(T)	35.60	1.796	6.02	**243.5**
Average					**247.2**

Table 3.10 The Table gives results from determination of detonation pressure by Plate Dent test for MCX-6002 Lot DDP13A0003E.

3.3.2 MCX-8001

For three test items of MCX-8001 Lot DDP13A0004E detonation pressure were determined by use of the Plate Dent test. Figure 3.25 shows the test setup and the Dent plate after firing for shot No 1. Unfortunately the test charge moved a little so the contact with the Dent plate was not optimal. This explains the deviation in Dent depth for this shot compared with the other four performed.

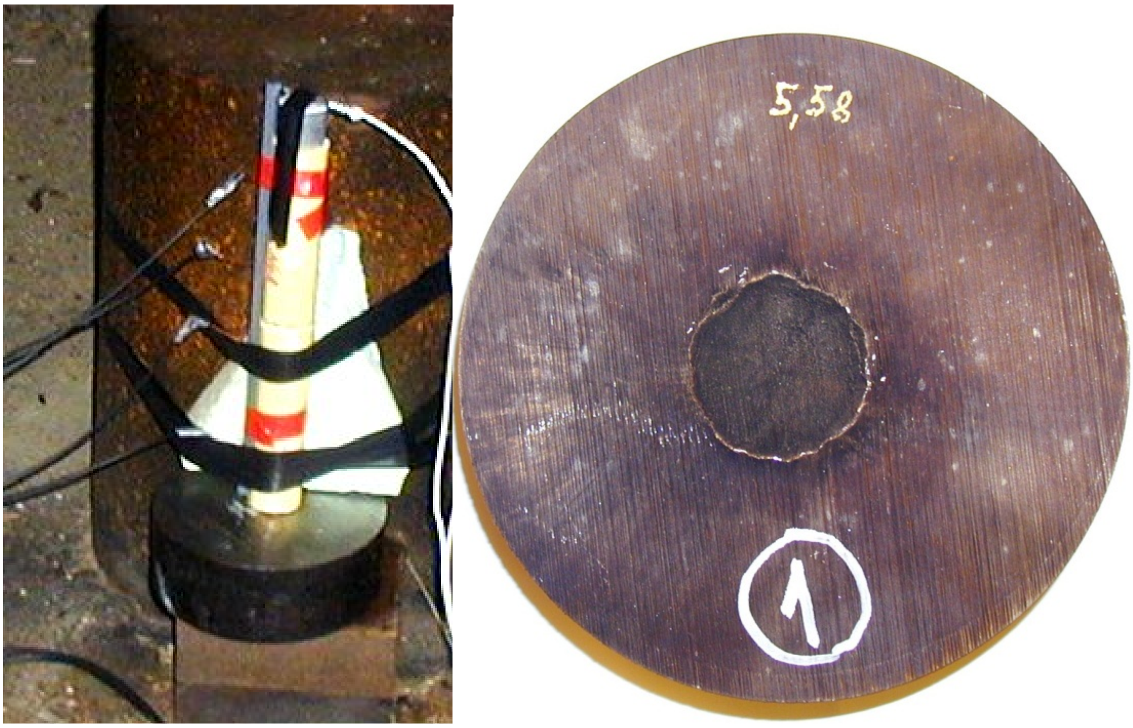

Figure 3.25 Left picture shows the test setup and the right picture the Dent plate after the firing.

Figure 3.26 shows test setup for shot 4 and 5 with MCX-8001 Lot DDP13A0004E and the Dent plates after firing. The results are given in Table 3.11 showing a detonation pressure of 244.4 kbar for shot 4 and of 247.1 kbar for shot 5. Both values are in the expected range.

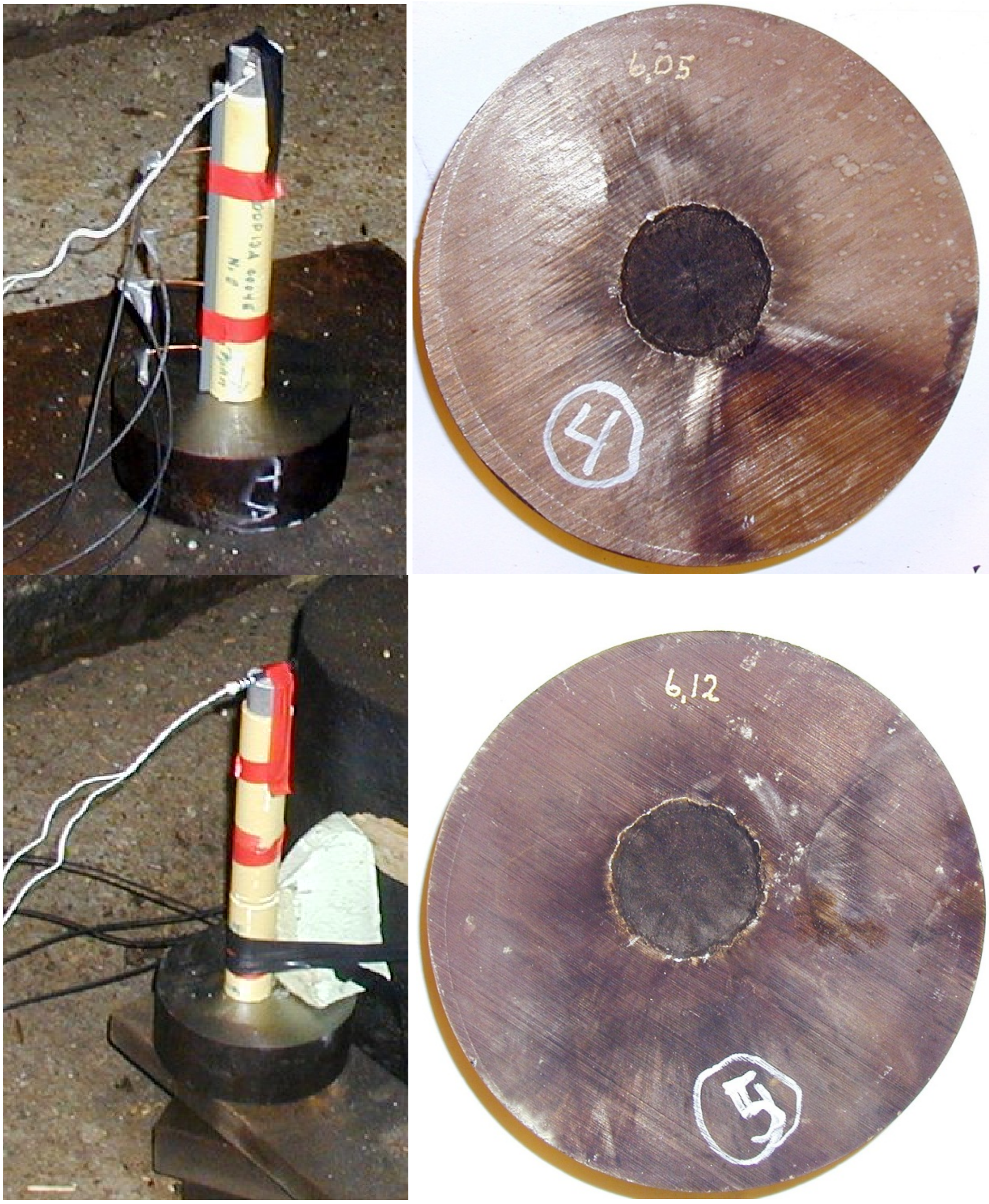

Figure 3.26 The Figure shows the setup and Dent plates after firing for the two tested charges containing the MCX 8001 composition Lot DDP13A0004E.

Shot No	From tube No	Charge diameter (mm)	Density (g/cm^3)	Dent Depth (mm)	Detonation pressure (kbar)
1	4	35.60	1.789	5.58	**225.7**
4	2	35.65	1.781	6.05	**244.4**
5	3 + 1	35.66	1.778	6.12	**247.1**
Average	**Shot 4 and 5**				**245.8**

Table 3.11 Results from determination of detonation pressure by Plate Dent test for MCX-8001 Lot DDP13A0004E.

3.4 Theoretical calculations

3.4.1 TMD

Cheetah 2.0 (15) has been used to calculate the performance of MCX-6002 and MCX-8001 compositions. Calculations have been done with both the BKWC and the BKWS libraries. Appendix C gives summary print outs for all calculations. Table 3.12 summarizes calculations at TMD for both compositions with both product libraries.

Property	BKWC Product Database		BKWS Product Database	
	MCX-6002[1]	MCX-8001[2]	MCX-6002	MCX-8001
TMD (g/cc)	1.7997	1.8087	1.7997	1.8087
The C-J condition:				
Pressure (GPa)	26.53	26.59	27.22	27.27
Volume (cc/g)	0.428	0.426	0.423	0.421
Density (g/cc)	2.338	2.348	2.362	2.374
Energy (kJ/cc explosive)	3.6	3.06	3.24	3.25
Temperature (K)	3626	3599	3589	3562
Shock velocity (m/s)	8001	7998	7970	7958
Particle velocity (m/s)	1843	1838	1898	1895
Speed of sound (m/s)	6159	6160	6072	6063
Gamma	3.342	3.351	3.200	3.200
Freezing occurred at T = 1800. K and relative V =	1.888	1.868	1.828	1.809
Mechanical energy of detonation (kJ/cc)	-8.388	-8.366	-8.167	-8.147
Thermal energy of detonation (kJ/cc)	-0.000	-0.000	-0.000	-0.000
Total energy of detonation (kJ/cc)	-8.388	-8.366	-8.167	-8.147

[1] MCX 6002: NTO/TNT/RDX (51/34/15). [2] MCX 8001: NTO/TNT/HMX (52/36/12).

Table 3.12 Different properties of tested compositions calculated by use of Cheetah 2.0 at TMD.

Detonation pressure and velocity for MCX-6002 and MCX-8001 were calculated by Cheetah giving approximately the same values with both product libraries. In addition both had the same detonation velocity and detonation pressure.

3.4.2 MCX-6002 different densities

Table 3.13 gives detonation pressure and velocity for different densities of MCX-6002 calculated with both the BKWC and BKWS product libraries. Figure 3.27 shows the same data in addition to experimentally measured properties. Experimentally measured detonation pressure and velocity for MCX-6002 firing No 2 cast No 3 were 250.8 kbar/7700 m/s (ρ =1.790 g/cm^3) and for firing No 3 cast No 4 243.5 kbar/7859 m/s (ρ=1.796 g/cm^3). In addition velocity given for firing No 2 cast No 2 was 7983 m/s (ρ =1.785 g/cm^3) and for firing No 3 cast No 1 7964 m/s (ρ =1.78 g/cm^3). Two of the measured detonation velocities are higher and two lower than calculated by Cheetah. Both experimentally measured detonation pressures are below calculations with Cheetah.

Density (g/cm^3)	Product Library BKWC		Product Library BKWS	
	Detonation		Detonation	
	Pressure (GPa)	Velocity (m/s)	Pressure (GPa)	Velocity (m/s)
1.7997	27.22	7970	26.53	8001
1.79	26.84	7936	26.18	7964
1.78	26.45	7901	25.83	7926
1.77	26.07	7866	25.47	7888
1.76	25.69	7831	25.13	7850
1.75	25.32	7797	24.78	7812
1.74	24.96	7762	24.44	7774
1.73	24.60	7727	24.10	7736
1.72	24.24	7692	23.77	7698
1.71	23.89	7657	23.44	7660
1.70	23.54	7622	23.12	7623
1.69	23.20	7587	22.79	7585
1.68	22.86	7553	22.48	7548

Table 3.13 Detonation pressure and velocity for different densities of MCX-6002 calculated with Cheetah 2.0.

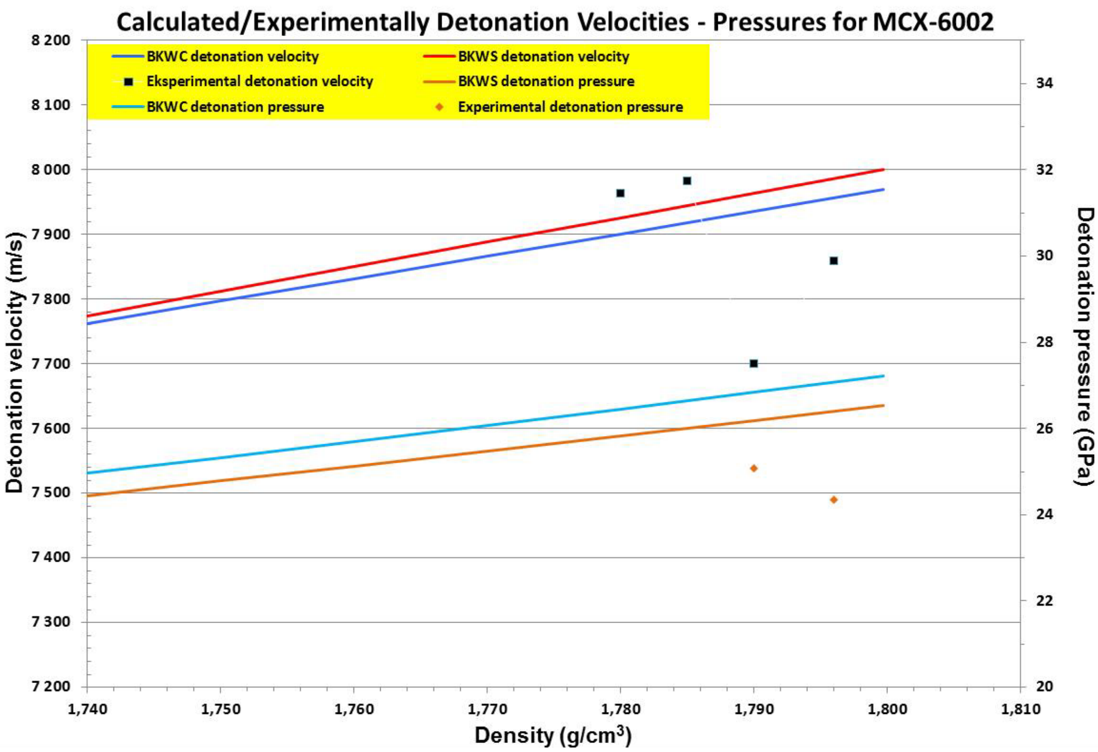

Figure 3.27 Calculated and measured detonation velocities and pressures for MCX-6002 as function of density.

3.4.3 MCX-8001 different densities

Table 3.14 summarizes detonation velocity and pressure for different densities calculated with Cheetah 2.0 (18) and both the BKWC and the BKWS product libraries. Figure 3.28 shows the same data in addition to the experimental results. Experimentally measured detonation pressures and velocities of MCX-8001 firing No 4 cast No 2 was 244.4 kbar/7672 m/s (ρ =1.781 g/cm^3) and for firing No 5 cast No 3 247.1 kbar/7426 m/s (ρ=1.758 g/cm^3).

Density (g/cm^3)	Product Library BKWC		Product Library BKWS	
	Detonation		Detonation	
	Pressure (GPa)	Velocity (m/s)	Pressure (GPa)	Velocity (m/s)
1.8087	27.27	7958	26.59	7998
1.79	26.54	7893	25.92	7927
1.78	26.16	7859	25.56	7888
1.77	25.78	7824	25.21	7850
1.76	25.40	7789	24.87	7812
1.75	25.03	7755	24.52	7774

Table 3.14 Detonation pressure and velocity for different densities of MCX-6002 calculated with Cheetah 2.0.

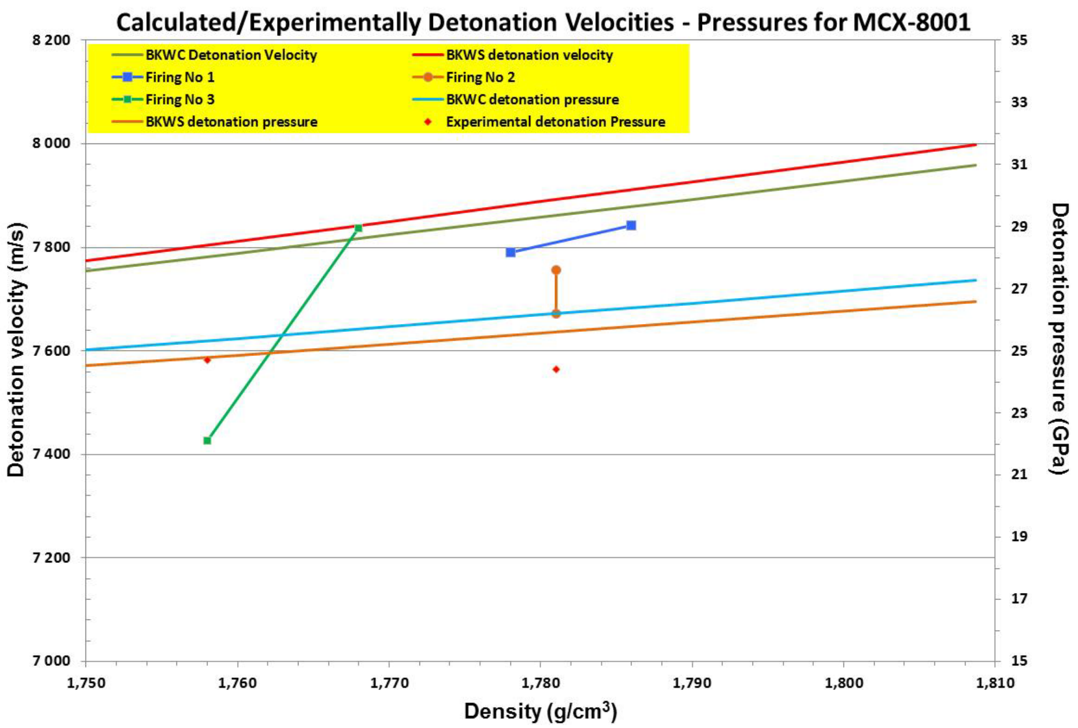

Figure 3.28 Calculated and measured detonation velocities and detonation pressures for MCX-8001 as function of density.

In addition the measured detonation velocity was plotted for firing No 1 cast No 3 at 7790 m/s (ρ =1.778 g/cm^3), for cast No 4 at 7842 m/s (ρ =1.786 g/cm^3) and for firing No 5 cast No 1 at 7836 m/s (ρ =1.768 g/cm^3). Out of the measured detonation velocities one is equal and five lower than calculated by Cheetah. For the experimentally measured detonation pressures one are lower and one equal to the calculated pressure with Cheetah.

4 Summary

Two melt-cast compositions MCX-6002 and MCX-8001 have been characterized. Cylindrical charges with diameter from 11 to 37 mm were casted. The quality of the charges was examined by X-ray. The X-ray pictures shows inclusion of air in all charges. The air inclusion is observed as porosity and pores/bubbles. For the charges with largest diameter even empty space is observed. However, the charges casted for detonation velocity and pressure determination had in the bottom a quality and density that could justify testing.

To determine critical diameter of MCX-6002 cylindrical charges of 5 different diameters were glued together to three test items with diameter from 11 mm to 26 mm. The results showed a critical diameter less than 11 mm for all test items. Three conical charges with diameter from 30 mm to 3-4 mm were also casted and tested. Average critical diameter for these test items was 10 mm.

For MCX-8001 charges of 5 different diameters were glued to three test items with diameter from 11 mm to 26 mm for testing of critical diameter. All test items had a critical diameter smaller than 11 mm.

Detonation velocity and pressure were tested with charges having diameter 36$\pm$ 2 mm. For both MCX-6002 and MCX-8001 4 charges were casted. Only the part of the charges having acceptable density was tested. Measured detonation velocities for MCX-6002: cast No 1 7964 m/s (ρ =1.78 g/cm^3), cast No 2 7983 m/s (ρ =1.785 g/cm^3), cast No 3 7700 m/s (ρ =1.790 g/cm^3) and for cast No 4 7859 m/s (ρ=1.796 g/cm^3). On average the detonation velocity is not very different from what is theoretically calculated. Two detonation pressure determinations with average pressure of 244.3 kbar are slightly below theoretically calculated.

Measured detonation velocity for MCX-8001: cast No 1 7836 m/s (ρ =1.768 g/cm^3), cast No 2 7700 m/s (ρ =1.781 g/cm^3), cast No 3 7426 m/s (ρ=1.758 g/cm^3) and 7790 m/s (ρ =1.778 g/cm^3) and cast No 4 7842 m/s (ρ =1.786 g/cm^3). On average measured detonation velocity is slightly below theoretically calculated. Two detonation pressure determinations with average pressure of 245.8 kbar are slightly below theoretically calculated.

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Appendix A Certificate for Dent Plates

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

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.

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**

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 16348	Diameter/dimensions 160 mm	Reduction ratio 5,71	Weight 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

Appendix B Control report HWC

Below figure 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 AS.

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

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

A.1 MCX-6002 - BKWC Product Library

A.1.1 TMD 1.7997 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)	
NTO	51.00	64.35	48.06	-24140	130.07	1.91	$C_2H_2N_4O_3$
RDX	15.00	11.08	14.95	16496	222.13	1.81	$C_3H_6N_6O_6$
TNT	34.00	24.57	37.00	-15057	227.13	1.65	$C_7H_5N_3O_6$

```
Density  =  1.7997 g/cc   Mixture TMD =  1.7997 g/cc   % TMD = 100.0000
```

The C-J condition:

```
The pressure          =          27.22 GPa
The volume            =          0.423 cc/g
The density           =          2.362 g/cc
The energy            =           3.24 kJ/cc explosive
The temperature       =           3589 K
The shock velocity    =          7.970 mm/us
The particle velocity =          1.898 mm/us
The speed of sound    =          6.072 mm/us
Gamma                 =          3.200
```

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	-0.96					
2.20	-5.22	108	82	70	58	120
4.10	-6.24	107	81	70	59	113
6.50	-6.67	107	80	71	60	109
10.00	-6.97	107	80	71	61	106
20.00	-7.31	106	80	72	62	102
40.00	-7.57	106	80	72	62	98
80.00	-7.78	106	80	73	63	94
160.00	-7.94					

```
Freezing occurred at T =      1800.0 K and relative V =   1.828
The mechanical energy of detonation =      -8.167 kJ/cc
The thermal energy of detonation    =      -0.000 kJ/cc
The total energy of detonation      =      -8.167 kJ/cc
```

JWL Fit results:

```
E0    =        -8.574 kJ/cc
A     =        870.64 GPa, B    =     8.20 GPa, C      =         1.14 GPa
R[1] =           4.80,      R[2] =     1.07,      omega =         0.33
RMS fitting error =   0.89 %
```

C.1.2 Density 1.79 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)	
NTO	51.00	64.35	48.06	-24140	130.07	1.91	$C_2H_2N_4O_3$
RDX	15.00	11.08	14.95	16496	222.13	1.81	$C_3H_6N_6O_6$
TNT	34.00	24.57	37.00	-15057	227.13	1.65	$C_7H_5N_3O_6$

Density = 1.7900 g/cc Mixture TMD = 1.7997 g/cc % TMD = 99.4586

The C-J condition:

The pressure	=	26.84 GPa
The volume	=	0.426 cc/g
The density	=	2.349 g/cc
The energy	=	3.19 kJ/cc explosive
The temperature	=	3593 K
The shock velocity	=	7.936 mm/us
The particle velocity	=	1.889 mm/us
The speed of sound	=	6.047 mm/us
Gamma	=	3.200

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	-0.95					
2.20	-5.16	106	81	69	57	118
4.10	-6.19	106	80	70	59	112
6.50	-6.62	106	80	70	59	108
10.00	-6.91	106	79	71	60	105
20.00	-7.25	106	79	71	61	101
40.00	-7.51	105	79	72	62	97
80.00	-7.72	105	79	72	62	94
160.00	-7.88					

Freezing occurred at T = 1800.0 K and relative V = 1.836
The mechanical energy of detonation = -8.107 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -8.107 kJ/cc

JWL Fit results:
E0 = -8.435 kJ/cc
A = 856.66 GPa, B = 8.08 GPa, C = 1.30 GPa
R[1] = 4.81, R[2] = 1.10, omega = 0.37
RMS fitting error = 0.68 %

C.1.3 Density 1.78 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)	
NTO	51.00	64.35	48.06	-24140	130.07	1.91	$C_2H_2N_4O_3$
RDX	15.00	11.08	14.95	16496	222.13	1.81	$C_3H_6N_6O_6$
TNT	34.00	24.57	37.00	-15057	227.13	1.65	$C_7H_5N_3O_6$

Density = 1.7800 g/cc   Mixture TMD = 1.7997 g/cc   % TMD = 98.9029

The C-J condition:

The pressure	=	26.45 GPa
The volume	=	0.428 cc/g
The density	=	2.336 g/cc
The energy	=	3.15 kJ/cc explosive
The temperature	=	3597 K
The shock velocity	=	7.901 mm/us
The particle velocity	=	1.881 mm/us
The speed of sound	=	6.020 mm/us
Gamma	=	3.201

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	-0.94					
2.20	-5.11	105	80	68	56	117
4.10	-6.13	105	79	69	58	111
6.50	-6.56	105	79	70	59	107
10.00	-6.85	105	79	70	60	104
20.00	-7.19	105	79	71	61	100
40.00	-7.45	104	78	71	61	96
80.00	-7.66	104	78	71	62	93
160.00	-7.82					

Freezing occurred at T = 1800.0 K and relative V = 1.844
The mechanical energy of detonation = -8.045 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -8.045 kJ/cc

JWL Fit results:
E0 = -8.449 kJ/cc
A = 849.42 GPa, B = 8.05 GPa, C = 1.13 GPa
R[1] = 4.81, R[2] = 1.07, omega = 0.33
RMS fitting error = 0.89 %

C.1.4 Density 1.77g/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)	
NTO	51.00	64.35	48.06	-24140	130.07	1.91	$C_2H_2N_4O_3$
RDX	15.00	11.08	14.95	16496	222.13	1.81	$C_3H_6N_6O_6$
TNT	34.00	24.57	37.00	-15057	227.13	1.65	$C_7H_5N_3O_6$

Density = 1.7700 g/cc   Mixture TMD = 1.7997 g/cc   % TMD = 98.3473

The C-J condition:

The pressure	=	26.07 GPa
The volume	=	0.430 cc/g
The density	=	2.323 g/cc
The energy	=	3.10 kJ/cc explosive
The temperature	=	3600 K
The shock velocity	=	7.866 mm/us
The particle velocity	=	1.872 mm/us
The speed of sound	=	5.994 mm/us
Gamma	=	3.201

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	-0.93					
2.20	-5.06	104	80	68	56	116
4.10	-6.07	104	79	68	57	110
6.50	-6.50	104	78	69	58	106
10.00	-6.78	104	78	69	59	103
20.00	-7.13	104	78	70	60	99
40.00	-7.39	103	78	71	61	96
80.00	-7.59	103	78	71	61	92
160.00	-7.76					

Freezing occurred at T = 1800.0 K and relative V = 1.852
The mechanical energy of detonation = -7.983 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -7.983 kJ/cc

JWL Fit results:
E0 = -8.309 kJ/cc
A = 834.55 GPa, B = 7.90 GPa, C = 1.29 GPa
R[1] = 4.82, R[2] = 1.10, omega = 0.37
RMS fitting error = 0.68 %

C.1.5 Density 1.76 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)	
NTO	51.00	64.35	48.06	-24140	130.07	1.91	$C_2H_2N_4O_3$
RDX	15.00	11.08	14.95	16496	222.13	1.81	$C_3H_6N_6O_6$
TNT	34.00	24.57	37.00	-15057	227.13	1.65	$C_7H_5N_3O_6$

Density = 1.7600 g/cc Mixture TMD = 1.7997 g/cc % TMD = 97.7917

The C-J condition:
The pressure = 25.69 GPa
The volume = 0.433 cc/g
The density = 2.310 g/cc
The energy = 3.06 kJ/cc explosive
The temperature = 3604 K
The shock velocity = 7.831 mm/us
The particle velocity = 1.864 mm/us
The speed of sound = 5.967 mm/us
Gamma = 3.201

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	-0.92					
2.20	-5.00	103	79	67	55	115
4.10	-6.01	103	78	68	57	109
6.50	-6.44	103	78	68	58	105
10.00	-6.72	103	77	69	59	103
20.00	-7.07	103	77	69	60	99
40.00	-7.33	103	77	70	60	95
80.00	-7.53	102	77	70	61	91
160.00	-7.70					

Freezing occurred at T = 1800.0 K and relative V = 1.859
The mechanical energy of detonation = -7.922 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -7.922 kJ/cc

JWL Fit results:
E0 = -8.322 kJ/cc
A = 826.91 GPa, B = 7.87 GPa, C = 1.13 GPa
R[1] = 4.82, R[2] = 1.06, omega = 0.33
RMS fitting error = 0.90 %

C.1.6 Density 1.75 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)	
NTO	51.00	64.35	48.06	-24140	130.07	1.91	$C_2H_2N_4O_3$
RDX	15.00	11.08	14.95	16496	222.13	1.81	$C_3H_6N_6O_6$
TNT	34.00	24.57	37.00	-15057	227.13	1.65	$C_7H_5N_3O_6$

Density = 1.7500 g/cc   Mixture TMD = 1.7997 g/cc   % TMD = 97.2360

The C-J condition:
The pressure = 25.32 GPa
The volume = 0.435 cc/g
The density = 2.297 g/cc
The energy = 3.01 kJ/cc explosive
The temperature = 3607 K
The shock velocity = 7.797 mm/us
The particle velocity = 1.856 mm/us
The speed of sound = 5.941 mm/us
Gamma = 3.201

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	-0.90					
2.20	-4.95	102	78	66	55	114
4.10	-5.95	102	77	67	56	108
6.50	-6.38	102	77	68	57	104
10.00	-6.66	102	77	68	58	102
20.00	-7.01	102	77	69	59	98
40.00	-7.27	102	77	69	60	94
80.00	-7.47	101	76	70	60	91
160.00	-7.63					

Freezing occurred at T = 1800.0 K and relative V = 1.867
The mechanical energy of detonation = -7.860 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -7.860 kJ/cc

JWL Fit results:
E0 = -8.184 kJ/cc
A = 812.10 GPa, B = 7.73 GPa, C = 1.29 GPa
R[1] = 4.82, R[2] = 1.10, omega = 0.37
RMS fitting error = 0.69 %

C.1.7 Density 1.74 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)	
NTO	51.00	64.35	48.06	-24140	130.07	1.91	$C_2H_2N_4O_3$
RDX	15.00	11.08	14.95	16496	222.13	1.81	$C_3H_6N_6O_6$
TNT	34.00	24.57	37.00	-15057	227.13	1.65	$C_7H_5N_3O_6$

Density = 1.7400 g/cc Mixture TMD = 1.7997 g/cc % TMD = 96.6804

The C-J condition:

The pressure	=	24.96 GPa
The volume	=	0.438 cc/g
The density	=	2.284 g/cc
The energy	=	2.97 kJ/cc explosive
The temperature	=	3610 K
The shock velocity	=	7.762 mm/us
The particle velocity	=	1.848 mm/us
The speed of sound	=	5.914 mm/us
Gamma	=	3.200

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	-0.89					
2.20	-4.90	101	77	66	54	112
4.10	-5.89	101	76	67	56	107
6.50	-6.32	101	76	67	57	103
10.00	-6.60	101	76	68	58	101
20.00	-6.95	101	76	68	58	97
40.00	-7.21	101	76	69	59	93
80.00	-7.41	101	76	69	60	90
160.00	-7.57					

Freezing occurred at T = 1800.0 K and relative V = 1.875
The mechanical energy of detonation = -7.799 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -7.799 kJ/cc

JWL Fit results:
E0 = -8.122 kJ/cc
A = 800.74 GPa, B = 7.64 GPa, C = 1.28 GPa
R[1] = 4.82, R[2] = 1.10, omega = 0.37
RMS fitting error = 0.69 %

C.1.8 Density 1.73 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)	
NTO	51.00	64.35	48.06	-24140	130.07	1.91	$C_2H_2N_4O_3$
RDX	15.00	11.08	14.95	16496	222.13	1.81	$C_3H_6N_6O_6$
TNT	34.00	24.57	37.00	-15057	227.13	1.65	$C_7H_5N_3O_6$

Density = 1.7300 g/cc Mixture TMD = 1.7997 g/cc % TMD = 96.1248

```
The C-J condition:
The pressure          =          24.60 GPa
The volume            =          0.440 cc/g
The density           =          2.271 g/cc
The energy            =           2.93 kJ/cc explosive
The temperature       =           3613 K
The shock velocity    =          7.727 mm/us
The particle velocity =          1.840 mm/us
The speed of sound    =          5.887 mm/us
Gamma                 =          3.199
```

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	-4.84	100	76	65	54	111
4.10	-5.84	100	76	66	55	106
6.50	-6.26	100	75	66	56	102
10.00	-6.55	100	75	67	57	100
20.00	-6.89	100	75	68	58	96
40.00	-7.15	100	75	68	59	92
80.00	-7.35	100	75	69	60	89
160.00	-7.51					

```
Freezing occurred at T =     1800.0 K and relative V =   1.883
The mechanical energy of detonation =     -7.737 kJ/cc
The thermal energy of detonation    =     -0.000 kJ/cc
The total energy of detonation      =     -7.737 kJ/cc
```

```
JWL Fit results:
E0   =       -8.059 kJ/cc
A    =       789.63 GPa, B    =      7.56 GPa, C     =         1.28 GPa
R[1] =         4.83,     R[2] =      1.10,     omega =         0.37
RMS fitting error =   0.69 %
```

C.1.9 Density 1.72 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)	
NTO	51.00	64.35	48.06	-24140	130.07	1.91	$C_2H_2N_4O_3$
RDX	15.00	11.08	14.95	16496	222.13	1.81	$C_3H_6N_6O_6$
TNT	34.00	24.57	37.00	-15057	227.13	1.65	$C_7H_5N_3O_6$

Density = 1.7200 g/cc   Mixture TMD = 1.7997 g/cc   % TMD = 95.5691

The C-J condition:
The pressure = 24.24 GPa
The volume = 0.443 cc/g
The density = 2.258 g/cc
The energy = 2.89 kJ/cc explosive
The temperature = 3616 K
The shock velocity = 7.692 mm/us
The particle velocity = 1.832 mm/us
The speed of sound = 5.860 mm/us
Gamma = 3.198

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	-0.87					
2.20	-4.79	99	75	64	53	110
4.10	-5.78	99	75	65	55	105
6.50	-6.20	100	75	66	56	101
10.00	-6.49	99	75	66	57	99
20.00	-6.83	99	75	67	57	95
40.00	-7.09	99	75	68	58	92
80.00	-7.29	99	75	68	59	88
160.00	-7.45					

Freezing occurred at T = 1800.0 K and relative V = 1.890
The mechanical energy of detonation = -7.676 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -7.676 kJ/cc

JWL Fit results:
E0 = -8.070 kJ/cc
A = 781.72 GPa, B = 7.54 GPa, C = 1.13 GPa
R[1] = 4.83, R[2] = 1.06, omega = 0.33
RMS fitting error = 0.90 %

C.1.10 Density 1.71 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)	
NTO	51.00	64.35	48.06	-24140	130.07	1.91	$C_2H_2N_4O_3$
RDX	15.00	11.08	14.95	16496	222.13	1.81	$C_3H_6N_6O_6$
TNT	34.00	24.57	37.00	-15057	227.13	1.65	$C_7H_5N_3O_6$

Density = 1.7100 g/cc   Mixture TMD = 1.7997 g/cc   % TMD = 95.0135

The C-J condition:

The pressure	=	23.89 GPa
The volume	=	0.445 cc/g
The density	=	2.245 g/cc
The energy	=	2.85 kJ/cc explosive
The temperature	=	3619 K
The shock velocity	=	7.657 mm/us
The particle velocity	=	1.824 mm/us
The speed of sound	=	5.833 mm/us
Gamma	=	3.197

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	-4.74	98	75	63	52	109
4.10	-5.72	99	74	65	54	104
6.50	-6.14	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	-7.03	98	74	67	58	91
80.00	-7.23	98	74	67	59	88
160.00	-7.39					

Freezing occurred at T = 1800.0 K and relative V = 1.898
The mechanical energy of detonation = -7.615 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -7.615 kJ/cc

JWL Fit results:
E0 = -7.935 kJ/cc
A = 768.23 GPa, B = 7.42 GPa, C = 1.28 GPa
R[1] = 4.83, R[2] = 1.10, omega = 0.37
RMS fitting error = 0.70 %

C.1.11 Density 1.70g/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)	
NTO	51.00	64.35	48.06	-24140	130.07	1.91	$C_2H_2N_4O_3$
RDX	15.00	11.08	14.95	16496	222.13	1.81	$C_3H_6N_6O_6$
TNT	34.00	24.57	37.00	-15057	227.13	1.65	$C_7H_5N_3O_6$

Density = 1.7000 g/cc Mixture TMD = 1.7997 g/cc % TMD = 94.4579

The C-J condition:
The pressure = 23.54 GPa
The volume = 0.448 cc/g
The density = 2.232 g/cc
The energy = 2.81 kJ/cc explosive
The temperature = 3622 K
The shock velocity = 7.622 mm/us
The particle velocity = 1.817 mm/us
The speed of sound = 5.806 mm/us
Gamma = 3.196

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	-4.69	97	74	63	52	108
4.10	-5.67	98	73	64	54	103
6.50	-6.08	98	73	65	55	100
10.00	-6.37	98	73	65	55	97
20.00	-6.71	98	73	66	56	94
40.00	-6.97	97	73	66	57	90
80.00	-7.17	97	73	67	58	87
160.00	-7.33					

Freezing occurred at T = 1800.0 K and relative V = 1.905
The mechanical energy of detonation = -7.554 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -7.554 kJ/cc

JWL Fit results:
E0 = -7.945 kJ/cc
A = 758.68 GPa, B = 7.37 GPa, C = 1.12 GPa
R[1] = 4.83, R[2] = 1.06, omega = 0.33
RMS fitting error = 0.90 %

C.1.12 Density 1.69 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)	
NTO	51.00	64.35	48.06	-24140	130.07	1.91	$C_2H_2N_4O_3$
RDX	15.00	11.08	14.95	16496	222.13	1.81	$C_3H_6N_6O_6$
TNT	34.00	24.57	37.00	-15057	227.13	1.65	$C_7H_5N_3O_6$

Density = 1.6900 g/cc Mixture TMD = 1.7997 g/cc % TMD = 93.9022

The C-J condition:
The pressure = 23.20 GPa
The volume = 0.451 cc/g
The density = 2.219 g/cc
The energy = 2.77 kJ/cc explosive
The temperature = 3624 K
The shock velocity = 7.587 mm/us
The particle velocity = 1.809 mm/us
The speed of sound = 5.778 mm/us
Gamma = 3.194

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	-4.64	96	73	62	51	106
4.10	-5.61	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	-7.11	96	73	66	58	86
160.00	-7.27					

Freezing occurred at T = 1800.0 K and relative V = 1.913
The mechanical energy of detonation = -7.493 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -7.493 kJ/cc

JWL Fit results:
E0 = -7.811 kJ/cc
A = 747.37 GPa, B = 7.29 GPa, C = 1.27 GPa
R[1] = 4.84, R[2] = 1.10, omega = 0.37
RMS fitting error = 0.70 %

C.1.13 Density 1.68 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)	
NTO	51.00	64.35	48.06	-24140	130.07	1.91	$C_2H_2N_4O_3$
RDX	15.00	11.08	14.95	16496	222.13	1.81	$C_3H_6N_6O_6$
TNT	34.00	24.57	37.00	-15057	227.13	1.65	$C_7H_5N_3O_6$

Density = 1.6800 g/cc   Mixture TMD = 1.7997 g/cc   **% TMD = 93.3466**

The C-J condition:

The pressure	=	22.86 GPa
The volume	=	0.453 cc/g
The density	=	2.206 g/cc
The energy	=	2.73 kJ/cc explosive
The temperature	=	3627 K
The shock velocity	=	7.553 mm/us
The particle velocity	=	1.802 mm/us
The speed of sound	=	5.751 mm/us
Gamma	=	3.192

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	-4.59	95	72	61	51	105
4.10	-5.56	96	72	63	53	101
6.50	-5.97	96	72	63	54	98
10.00	-6.25	96	72	64	54	95
20.00	-6.59	96	72	65	55	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 = 1.920
The mechanical energy of detonation = -7.433 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -7.433 kJ/cc

JWL Fit results:

E0 = -7.820 kJ/cc
A = 735.57 GPa, B = 7.20 GPa, C = 1.12 GPa
R[1] = 4.83, R[2] = 1.06, omega = 0.33
RMS fitting error = 0.90 %

C.2 MCX 8001 – BKWC Product Library

C.2.1 TMD 1.8087 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)	
NTO	52.00	66.76	49.24	-24140	130.07	1.91	$C_2H_2N_4O_3$
TNT	36.00	26.47	39.37	-15057	227.13	1.65	$C_7H_5N_3O_6$
HMX	12.00	6.77	11.39	17866	296.17	1.91	$C_4H_8N_8O_8$

Density = 1.8087 g/cc   Mixture TMD = 1.8087 g/cc   % TMD = 100.0000

The C-J condition:

The pressure	=	27.27 GPa
The volume	=	0.421 cc/g
The density	=	2.374 g/cc
The energy	=	3.25 kJ/cc explosive
The temperature	=	3562 K
The shock velocity	=	7.958 mm/us
The particle velocity	=	1.895 mm/us
The speed of sound	=	6.063 mm/us
Gamma	=	3.200

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	-0.96					
2.20	-5.20	107	82	70	57	119
4.10	-6.22	107	81	70	59	113
6.50	-6.65	107	80	71	60	109
10.00	-6.94	106	80	71	60	106
20.00	-7.29	106	80	71	61	102
40.00	-7.55	106	79	72	62	98
80.00	-7.75	105	79	72	63	94
160.00	-7.92					

Freezing occurred at T = 1800.0 K and relative V = 1.809
The mechanical energy of detonation = -8.147 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -8.147 kJ/cc

JWL Fit results:
E0 = -8.477 kJ/cc
A = 869.16 GPa, B = 8.13 GPa, C = 1.28 GPa
R[1] = 4.80, R[2] = 1.11, omega = 0.36
RMS fitting error = 0.67 %

C.2.2 Density 1.79 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)	
NTO	52.00	66.76	49.24	-24140	130.07	1.91	$C_2H_2N_4O_3$
TNT	36.00	26.47	39.37	-15057	227.13	1.65	$C_7H_5N_3O_6$
HMX	12.00	6.77	11.39	17866	296.17	1.91	$C_4H_8N_8O_8$

Density = 1.7900 g/cc   Mixture TMD = 1.8087 g/cc   **% TMD = 98.9687**

The C-J condition:

The pressure	=	26.54 GPa
The volume	=	0.426 cc/g
The density	=	2.349 g/cc
The energy	=	3.16 kJ/cc explosive
The temperature	=	3569 K
The shock velocity	=	7.893 mm/us
The particle velocity	=	1.878 mm/us
The speed of sound	=	6.015 mm/us
Gamma	=	3.202

Cylinder runs:

V/V0 (rel.)	Energy (kJ/cc)	% of standards TATB 1.83g/cc	PETN 1.76g/cc	HMX 1.89g/cc	CL-20 2.04g/cc	TRITON 1.70g/cc
1.00	-0.94					
2.20	-5.10	105	80	68	56	117
4.10	-6.11	105	79	69	58	111
6.50	-6.54	105	79	69	59	107
10.00	-6.83	105	79	70	59	104
20.00	-7.17	104	78	70	60	100
40.00	-7.43	104	78	71	61	96
80.00	-7.64	104	78	71	62	93
160.00	-7.80					

Freezing occurred at T = 1800.0 K and relative V = 1.824
The mechanical energy of detonation = -8.032 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -8.032 kJ/cc

JWL Fit results:

E0 = -8.360 kJ/cc
A = 849.37 GPa, B = 7.97 GPa, C = 1.28 GPa
R[1] = 4.81, R[2] = 1.10, omega = 0.36
RMS fitting error = 0.67 %

C.2.3 Density 1.78 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)	
NTO	52.00	66.76	49.24	-24140	130.07	1.91	$C_2H_2N_4O_3$
TNT	36.00	26.47	39.37	-15057	227.13	1.65	$C_7H_5N_3O_6$
HMX	12.00	6.77	11.39	17866	296.17	1.91	$C_4H_8N_8O_8$

Density = 1.7800 g/cc   Mixture TMD = 1.8087 g/cc   % TMD = 98.4158

The C-J condition:

The pressure	=	26.16 GPa
The volume	=	0.428 cc/g
The density	=	2.336 g/cc
The energy	=	3.11 kJ/cc explosive
The temperature	=	3572 K
The shock velocity	=	7.859 mm/us
The particle velocity	=	1.870 mm/us
The speed of sound	=	5.989 mm/us
Gamma	=	3.203

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	-0.93					
2.20	-5.05	104	79	68	56	116
4.10	-6.05	104	78	68	57	110
6.50	-6.48	104	78	69	58	106
10.00	-6.77	104	78	69	59	103
20.00	-7.11	103	78	70	60	99
40.00	-7.37	103	78	70	61	95
80.00	-7.57	103	78	71	61	92
160.00	-7.74					

Freezing occurred at T = 1800.0 K and relative V = 1.831
The mechanical energy of detonation = -7.971 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -7.971 kJ/cc

JWL Fit results:
E0 = -8.376 kJ/cc
A = 842.40 GPa, B = 7.94 GPa, C = 1.12 GPa
R[1] = 4.82, R[2] = 1.06, omega = 0.33
RMS fitting error = 0.89 %

C.2.4 Density 1.77 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)	
NTO	52.00	66.76	49.24	-24140	130.07	1.91	$C_2H_2N_4O_3$
TNT	36.00	26.47	39.37	-15057	227.13	1.65	$C_7H_5N_3O_6$
HMX	12.00	6.77	11.39	17866	296.17	1.91	$C_4H_8N_8O_8$

Density = 1.7700 g/cc Mixture TMD = 1.8087 g/cc % TMD = 97.8629

The C-J condition:

The pressure	=	25.78 GPa
The volume	=	0.431 cc/g
The density	=	2.323 g/cc
The energy	=	3.07 kJ/cc explosive
The temperature	=	3576 K
The shock velocity	=	7.824 mm/us
The particle velocity	=	1.861 mm/us
The speed of sound	=	5.963 mm/us
Gamma	=	3.203

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	-0.92					
2.20	-4.99	103	79	67	55	115
4.10	-5.99	103	78	68	57	109
6.50	-6.42	103	77	68	58	105
10.00	-6.71	103	77	69	58	102
20.00	-7.05	103	77	69	59	98
40.00	-7.31	102	77	70	60	95
80.00	-7.51	102	77	70	61	91
160.00	-7.68					

Freezing occurred at T = 1800.0 K and relative V = 1.839
The mechanical energy of detonation = -7.910 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -7.910 kJ/cc

JWL Fit results:
E0 = -8.236 kJ/cc
A = 827.70 GPa, B = 7.79 GPa, C = 1.27 GPa
R[1] = 4.82, R[2] = 1.10, omega = 0.36
RMS fitting error = 0.68 %

C.2.5 Density 1.76 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)	
NTO	52.00	66.76	49.24	-24140	130.07	1.91	$C_2H_2N_4O_3$
TNT	36.00	26.47	39.37	-15057	227.13	1.65	$C_7H_5N_3O_6$
HMX	12.00	6.77	11.39	17866	296.17	1.91	$C_4H_8N_8O_8$

Density = 1.7600 g/cc   Mixture TMD = 1.8087 g/cc   % TMD = 97.3100

The C-J condition:

The pressure	=	25.40 GPa
The volume	=	0.433 cc/g
The density	=	2.309 g/cc
The energy	=	3.02 kJ/cc explosive
The temperature	=	3579 K
The shock velocity	=	7.789 mm/us
The particle velocity	=	1.853 mm/us
The speed of sound	=	5.936 mm/us
Gamma	=	3.204

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	-0.90					
2.20	-4.94	102	78	66	55	113
4.10	-5.94	102	77	67	56	108
6.50	-6.36	102	77	67	57	104
10.00	-6.65	102	76	68	58	101
20.00	-6.99	102	76	69	59	97
40.00	-7.25	101	76	69	60	94
80.00	-7.45	101	76	70	60	90
160.00	-7.62					

Freezing occurred at T = 1800.0 K and relative V = 1.847
The mechanical energy of detonation = -7.849 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -7.849 kJ/cc

JWL Fit results:
E0 = -8.250 kJ/cc
A = 820.15 GPa, B = 7.76 GPa, C = 1.12 GPa
R[1] = 4.82, R[2] = 1.06, omega = 0.33
RMS fitting error = 0.89 %

C.2.6 Density 1.75 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)	
NTO	52.00	66.76	49.24	-24140	130.07	1.91	$C_2H_2N_4O_3$
TNT	36.00	26.47	39.37	-15057	227.13	1.65	$C_7H_5N_3O_6$
HMX	12.00	6.77	11.39	17866	296.17	1.91	$C_4H_8N_8O_8$

Density = 1.7500 g/cc Mixture TMD = 1.8087 g/cc % TMD = 96.7571

The C-J condition:

The pressure	=	25.03 GPa
The volume	=	0.435 cc/g
The density	=	2.296 g/cc
The energy	=	2.98 kJ/cc explosive
The temperature	=	3582 K
The shock velocity	=	7.755 mm/us
The particle velocity	=	1.845 mm/us
The speed of sound	=	5.910 mm/us
Gamma	=	3.203

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	-0.89					
2.20	-4.89	101	77	65	54	112
4.10	-5.88	101	76	66	56	106
6.50	-6.30	101	76	67	57	103
10.00	-6.59	101	76	67	57	100
20.00	-6.93	101	76	68	58	97
40.00	-7.19	101	76	69	59	93
80.00	-7.39	100	76	69	60	90
160.00	-7.55					

Freezing occurred at T = 1800.0 K and relative V = 1.855
The mechanical energy of detonation = -7.788 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -7.788 kJ/cc

JWL Fit results:
E0 = -8.112 kJ/cc
A = 805.60 GPa, B = 7.62 GPa, C = 1.27 GPa
R[1] = 4.82, R[2] = 1.10, omega = 0.36
RMS fitting error = 0.68 %

C.3 MCX-6002 – BKWS Product Library

C.3.1 TMD 1.7997 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	51.00	64.35	48.06	-24140	130.07	1.91	$C_2H_2N_4O_3$
RDX	15.00	11.08	14.95	16496	222.13	1.81	$C_3H_6N_6O_6$
TNT	34.00	24.57	37.00	-15057	227.13	1.65	$C_7H_5N_3O_6$

Density = 1.7997 g/cc Mixture TMD = 1.7997 g/cc % TMD = 100.0000

The C-J condition:

The pressure	=	26.53 GPa
The volume	=	0.428 cc/g
The density	=	2.338 g/cc
The energy	=	3.06 kJ/cc explosive
The temperature	=	3626 K
The shock velocity	=	8.001 mm/us
The particle velocity	=	1.843 mm/us
The speed of sound	=	6.159 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	-0.95					
2.20	-5.35	110	84	72	59	123
4.10	-6.42	110	83	72	61	116
6.50	-6.87	110	83	73	62	112
10.00	-7.16	110	82	73	62	109
20.00	-7.51	109	82	74	63	105
40.00	-7.78	109	82	74	64	101
80.00	-7.98	108	82	75	65	97
160.00	-8.15					

Freezing occurred at T = 1800.0 K and relative V = 1.888
The mechanical energy of detonation = -8.388 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -8.388 kJ/cc

JWL Fit results:
E0 = -8.693 kJ/cc
A = 1008.11 GPa, B = 9.16 GPa, C = 1.32 GPa
R[1] = 5.00, R[2] = 1.11, omega = 0.37
RMS fitting error = 0.91 %

C.3.2 Density 1.79 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	51.00	64.35	48.06	-24140	130.07	1.91	$C_2H_2N_4O_3$
RDX	15.00	11.08	14.95	16496	222.13	1.81	$C_3H_6N_6O_6$
TNT	34.00	24.57	37.00	-15057	227.13	1.65	$C_7H_5N_3O_6$

Density = 1.7900 g/cc   Mixture TMD = 1.7997 g/cc   **% TMD = 99.4586**

The C-J condition:

The pressure	=	26.18 GPa
The volume	=	0.430 cc/g
The density	=	2.327 g/cc
The energy	=	3.02 kJ/cc explosive
The temperature	=	3631 K
The shock velocity	=	7.964 mm/us
The particle velocity	=	1.837 mm/us
The speed of sound	=	6.127 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	-0.94					
2.20	-5.30	109	83	71	59	121
4.10	-6.36	110	82	72	60	115
6.50	-6.81	109	82	72	61	111
10.00	-7.10	109	82	73	62	108
20.00	-7.45	109	81	73	63	104
40.00	-7.72	108	81	74	64	100
80.00	-7.92	107	81	74	64	96
160.00	-8.09					

Freezing occurred at T = 1800.0 K and relative V = 1.896
The mechanical energy of detonation = -8.329 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -8.329 kJ/cc

JWL Fit results:
E0 = -8.720 kJ/cc
A = 967.97 GPa, B = 8.73 GPa, C = 1.14 GPa
R[1] = 4.94, R[2] = 1.06, omega = 0.33
RMS fitting error = 1.12 %

C.3.3 Density 1.78 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	51.00	64.35	48.06	-24140	130.07	1.91	$C_2H_2N_4O_3$
RDX	15.00	11.08	14.95	16496	222.13	1.81	$C_3H_6N_6O_6$
TNT	34.00	24.57	37.00	-15057	227.13	1.65	$C_7H_5N_3O_6$

Density = 1.7800 g/cc   Mixture TMD = 1.7997 g/cc   % TMD = 98.9029

The C-J condition:

The pressure	=	25.83 GPa
The volume	=	0.432 cc/g
The density	=	2.315 g/cc
The energy	=	2.98 kJ/cc explosive
The temperature	=	3636 K
The shock velocity	=	7.926 mm/us
The particle velocity	=	1.831 mm/us
The speed of sound	=	6.095 mm/us
Gamma	=	3.329

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	-0.93					
2.20	-5.24	108	83	70	58	120
4.10	-6.30	109	82	71	60	114
6.50	-6.75	108	81	72	61	110
10.00	-7.04	108	81	72	61	107
20.00	-7.39	108	81	73	62	103
40.00	-7.65	107	81	73	63	99
80.00	-7.86	107	80	73	64	95
160.00	-8.02					

Freezing occurred at T = 1800.0 K and relative V = 1.904
The mechanical energy of detonation = -8.268 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -8.268 kJ/cc

JWL Fit results:
E0 = -8.658 kJ/cc
A = 949.35 GPa, B = 8.64 GPa, C = 1.14 GPa
R[1] = 4.94, R[2] = 1.06, omega = 0.33
RMS fitting error = 1.12 %

C.3.4 Density 1.77 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	51.00	64.35	48.06	-24140	130.07	1.91	$C_2H_2N_4O_3$
RDX	15.00	11.08	14.95	16496	222.13	1.81	$C_3H_6N_6O_6$
TNT	34.00	24.57	37.00	-15057	227.13	1.65	$C_7H_5N_3O_6$

Density = 1.7700 g/cc   Mixture TMD = 1.7997 g/cc   **% TMD = 98.3473**

The C-J condition:

The pressure	=	25.47 GPa
The volume	=	0.434 cc/g
The density	=	2.303 g/cc
The energy	=	2.95 kJ/cc explosive
The temperature	=	3640 K
The shock velocity	=	7.888 mm/us
The particle velocity	=	1.825 mm/us
The speed of sound	=	6.063 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	-0.92					
2.20	-5.19	107	82	69	57	119
4.10	-6.25	108	81	71	59	113
6.50	-6.69	107	81	71	60	109
10.00	-6.98	107	80	71	61	106
20.00	-7.33	107	80	72	62	102
40.00	-7.59	106	80	72	62	98
80.00	-7.80	106	80	73	63	95
160.00	-7.96					

Freezing occurred at T = 1800.0 K and relative V = 1.913
The mechanical energy of detonation = -8.208 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -8.208 kJ/cc

JWL Fit results:

E0 = -8.511 kJ/cc
A = 955.04 GPa, B = 8.91 GPa, C = 1.31 GPa
R[1] = 5.00, R[2] = 1.11, omega = 0.37
RMS fitting error = 0.90 %

C.3.5 Density 1.76 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	51.00	64.35	48.06	-24140	130.07	1.91	$C_2H_2N_4O_3$
RDX	15.00	11.08	14.95	16496	222.13	1.81	$C_3H_6N_6O_6$
TNT	34.00	24.57	37.00	-15057	227.13	1.65	$C_7H_5N_3O_6$

Density = 1.7600 g/cc   Mixture TMD = 1.7997 g/cc   **% TMD = 97.7917**

The C-J condition:

The pressure	=	25.13 GPa
The volume	=	0.437 cc/g
The density	=	2.291 g/cc
The energy	=	2.91 kJ/cc explosive
The temperature	=	3645 K
The shock velocity	=	7.850 mm/us
The particle velocity	=	1.819 mm/us
The speed of sound	=	6.031 mm/us
Gamma	=	3.316

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	-0.91					
2.20	-5.14	106	81	69	57	118
4.10	-6.19	107	80	70	59	112
6.50	-6.63	106	80	70	60	108
10.00	-6.92	106	80	71	60	106
20.00	-7.27	106	79	71	61	101
40.00	-7.53	105	79	72	62	97
80.00	-7.74	105	79	72	63	94
160.00	-7.90					

Freezing occurred at T = 1800.0 K and relative V = 1.921
The mechanical energy of detonation = -8.147 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -8.147 kJ/cc

JWL Fit results:

E0 = -8.449 kJ/cc
A = 937.02 GPa, B = 8.82 GPa, C = 1.31 GPa
R[1] = 4.99, R[2] = 1.11, omega = 0.37
RMS fitting error = 0.90 %

C.3.6 Density 1.75 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	51.00	64.35	48.06	-24140	130.07	1.91	$C_2H_2N_4O_3$
RDX	15.00	11.08	14.95	16496	222.13	1.81	$C_3H_6N_6O_6$
TNT	34.00	24.57	37.00	-15057	227.13	1.65	$C_7H_5N_3O_6$

Density = 1.7500 g/cc   Mixture TMD = 1.7997 g/cc   **% TMD = 97.2360**

The C-J condition:

The pressure	=	24.78 GPa
The volume	=	0.439 cc/g
The density	=	2.279 g/cc
The energy	=	2.88 kJ/cc explosive
The temperature	=	3650 K
The shock velocity	=	7.812 mm/us
The particle velocity	=	1.813 mm/us
The speed of sound	=	5.999 mm/us
Gamma	=	3.309

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	-0.90					
2.20	-5.08	105	80	68	56	117
4.10	-6.13	106	79	69	58	111
6.50	-6.57	105	79	70	59	108
10.00	-6.86	105	79	70	60	105
20.00	-7.21	105	79	71	61	101
40.00	-7.47	105	79	71	62	97
80.00	-7.68	104	79	72	62	93
160.00	-7.84					

Freezing occurred at T = 1800.0 K and relative V = 1.929
The mechanical energy of detonation = -8.087 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -8.087 kJ/cc

JWL Fit results:

E0 = -8.388 kJ/cc
A = 920.16 GPa, B = 8.74 GPa, C = 1.31 GPa
R[1] = 4.99, R[2] = 1.11, omega = 0.37
RMS fitting error = 0.90 %

C.3.7 Density 1.74 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 (cal/mol)	Mol.	TMD	
NTO	51.00	64.35	48.06	-24140	130.07	1.91	$C_2H_2N_4O_3$
RDX	15.00	11.08	14.95	16496	222.13	1.81	$C_3H_6N_6O_6$
TNT	34.00	24.57	37.00	-15057	227.13	1.65	$C_7H_5N_3O_6$

Density = 1.7400 g/cc   Mixture TMD = 1.7997 g/cc   **% TMD = 96.6804**

The C-J condition:

The pressure	=	24.44 GPa
The volume	=	0.441 cc/g
The density	=	2.267 g/cc
The energy	=	2.84 kJ/cc explosive
The temperature	=	3654 K
The shock velocity	=	7.774 mm/us
The particle velocity	=	1.807 mm/us
The speed of sound	=	5.967 mm/us
Gamma	=	3.302

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	-0.89					
2.20	-5.03	104	79	67	56	115
4.10	-6.07	105	79	69	58	110
6.50	-6.51	105	78	69	58	107
10.00	-6.80	104	78	70	59	104
20.00	-7.15	104	78	70	60	100
40.00	-7.41	104	78	71	61	96
80.00	-7.62	103	78	71	62	92
160.00	-7.78					

Freezing occurred at T = 1800.0 K and relative V = 1.937
The mechanical energy of detonation = -8.027 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -8.027 kJ/cc

JWL Fit results:

E0 = -8.327 kJ/cc
A = 902.80 GPa, B = 8.66 GPa, C = 1.30 GPa
R[1] = 4.99, R[2] = 1.11, omega = 0.37
RMS fitting error = 0.90 %

C.3.8 Density 1.73 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	51.00	64.35	48.06	-24140	130.07	1.91	$C_2H_2N_4O_3$
RDX	15.00	11.08	14.95	16496	222.13	1.81	$C_3H_6N_6O_6$
TNT	34.00	24.57	37.00	-15057	227.13	1.65	$C_7H_5N_3O_6$

Density = 1.7300 g/cc   Mixture TMD = 1.7997 g/cc   **% TMD = 96.1248**

The C-J condition:

The pressure	=	24.10 GPa
The volume	=	0.443 cc/g
The density	=	2.255 g/cc
The energy	=	2.81 kJ/cc explosive
The temperature	=	3659 K
The shock velocity	=	7.736 mm/us
The particle velocity	=	1.801 mm/us
The speed of sound	=	5.935 mm/us
Gamma	=	3.295

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	-4.98	103	78	67	55	114
4.10	-6.02	104	78	68	57	109
6.50	-6.45	104	78	68	58	106
10.00	-6.75	103	78	69	59	103
20.00	-7.09	103	77	70	60	99
40.00	-7.35	103	77	70	61	95
80.00	-7.56	103	77	71	61	92
160.00	-7.72					

Freezing occurred at T = 1800.0 K and relative V = 1.945
The mechanical energy of detonation = -7.966 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -7.966 kJ/cc

JWL Fit results:

E0 = -8.265 kJ/cc
A = 886.04 GPa, B = 8.58 GPa, C = 1.30 GPa
R[1] = 4.99, R[2] = 1.11, omega = 0.37
RMS fitting error = 0.89 %

C.3.9 Density 1.72 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	51.00	64.35	48.06	-24140	130.07	1.91	$C_2H_2N_4O_3$
RDX	15.00	11.08	14.95	16496	222.13	1.81	$C_3H_6N_6O_6$
TNT	34.00	24.57	37.00	-15057	227.13	1.65	$C_7H_5N_3O_6$

Density = 1.7200 g/cc   Mixture TMD = 1.7997 g/cc   **% TMD = 95.5691**

The C-J condition:

The pressure	=	23.77 GPa
The volume	=	0.446 cc/g
The density	=	2.243 g/cc
The energy	=	2.77 kJ/cc explosive
The temperature	=	3663 K
The shock velocity	=	7.698 mm/us
The particle velocity	=	1.795 mm/us
The speed of sound	=	5.903 mm/us
Gamma	=	3.288

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	-0.87					
2.20	-4.93	102	78	66	54	113
4.10	-5.96	103	77	67	56	108
6.50	-6.39	103	77	68	57	105
10.00	-6.69	103	77	68	58	102
20.00	-7.03	102	77	69	59	98
40.00	-7.29	102	77	70	60	94
80.00	-7.50	102	77	70	61	91
160.00	-7.66					

Freezing occurred at T = 1800.0 K and relative V = 1.952
The mechanical energy of detonation = -7.906 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -7.906 kJ/cc

JWL Fit results:

E0 = -8.288 kJ/cc
A = 843.33 GPa, B = 8.09 GPa, C = 1.12 GPa
R[1] = 4.92, R[2] = 1.05, omega = 0.33
RMS fitting error = 1.11 %

C.3.10 Density 1.71 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	51.00	64.35	48.06	-24140	130.07	1.91	$C_2H_2N_4O_3$
RDX	15.00	11.08	14.95	16496	222.13	1.81	$C_3H_6N_6O_6$
TNT	34.00	24.57	37.00	-15057	227.13	1.65	$C_7H_5N_3O_6$

Density = 1.7100 g/cc Mixture TMD = 1.7997 g/cc **% TMD = 95.0135**

The C-J condition:

The pressure	=	23.44 GPa
The volume	=	0.448 cc/g
The density	=	2.231 g/cc
The energy	=	2.74 kJ/cc explosive
The temperature	=	3668 K
The shock velocity	=	7.660 mm/us
The particle velocity	=	1.790 mm/us
The speed of sound	=	5.871 mm/us
Gamma	=	3.281

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	-4.88	101	77	65	54	112
4.10	-5.90	102	76	67	56	107
6.50	-6.34	102	76	67	57	104
10.00	-6.63	102	76	68	58	101
20.00	-6.97	102	76	68	59	97
40.00	-7.23	101	76	69	60	94
80.00	-7.44	101	76	69	60	90
160.00	-7.60					

Freezing occurred at T = 1800.0 K and relative V = 1.960
The mechanical energy of detonation = -7.846 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -7.846 kJ/cc

JWL Fit results:

E0 = -8.226 kJ/cc
A = 827.08 GPa, B = 8.02 GPa, C = 1.12 GPa
R[1] = 4.92, R[2] = 1.05, omega = 0.33
RMS fitting error = 1.11 %

C.3.11 Density 1.70 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	51.00	64.35	48.06	-24140	130.07	1.91	$C_2H_2N_4O_3$
RDX	15.00	11.08	14.95	16496	222.13	1.81	$C_3H_6N_6O_6$
TNT	34.00	24.57	37.00	-15057	227.13	1.65	$C_7H_5N_3O_6$

Density = 1.7000 g/cc   Mixture TMD = 1.7997 g/cc   **% TMD = 94.4579**

The C-J condition:

The pressure	=	23.12 GPa
The volume	=	0.451 cc/g
The density	=	2.219 g/cc
The energy	=	2.70 kJ/cc explosive
The temperature	=	3672 K
The shock velocity	=	7.623 mm/us
The particle velocity	=	1.784 mm/us
The speed of sound	=	5.839 mm/us
Gamma	=	3.273

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	-4.83	100	76	65	53	111
4.10	-5.85	101	76	66	55	106
6.50	-6.28	101	76	67	56	103
10.00	-6.57	101	76	67	57	100
20.00	-6.92	101	75	68	58	96
40.00	-7.17	100	76	68	59	93
80.00	-7.38	100	75	69	60	90
160.00	-7.54					

Freezing occurred at T = 1800.0 K and relative V = 1.968
The mechanical energy of detonation = -7.785 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -7.785 kJ/cc

JWL Fit results:

E0 = -8.082 kJ/cc
A = 836.37 GPa, B = 8.33 GPa, C = 1.29 GPa
R[1] = 4.99, R[2] = 1.11, omega = 0.37
RMS fitting error = 0.89 %

C.3.12 Density 1.69 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	51.00	64.35	48.06	-24140	130.07	1.91	$C_2H_2N_4O_3$
RDX	15.00	11.08	14.95	16496	222.13	1.81	$C_3H_6N_6O_6$
TNT	34.00	24.57	37.00	-15057	227.13	1.65	$C_7H_5N_3O_6$

Density = 1.6900 g/cc Mixture TMD = 1.7997 g/cc **% TMD = 93.9022**

The C-J condition:

The pressure	=	22.79 GPa
The volume	=	0.453 cc/g
The density	=	2.207 g/cc
The energy	=	2.67 kJ/cc explosive
The temperature	=	3676 K
The shock velocity	=	7.585 mm/us
The particle velocity	=	1.778 mm/us
The speed of sound	=	5.807 mm/us
Gamma	=	3.266

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	-4.78	99	75	64	53	110
4.10	-5.79	100	75	65	55	105
6.50	-6.22	100	75	66	56	102
10.00	-6.51	100	75	67	57	99
20.00	-6.86	100	75	67	58	96
40.00	-7.11	99	75	68	59	92
80.00	-7.32	99	75	68	59	89
160.00	-7.48					

Freezing occurred at T = 1800.0 K and relative V = 1.975
The mechanical energy of detonation = -7.725 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -7.725 kJ/cc

JWL Fit results:

E0 = -8.103 kJ/cc
A = 795.22 GPa, B = 7.86 GPa, C = 1.12 GPa
R[1] = 4.91, R[2] = 1.05 omega = 0.33
RMS fitting error = 1.11 %

C.3.13 Density 1.68 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	51.00	64.35	48.06	-24140	130.07	1.91	$C_2H_2N_4O_3$
RDX	15.00	11.08	14.95	16496	222.13	1.81	$C_3H_6N_6O_6$
TNT	34.00	24.57	37.00	-15057	227.13	1.65	$C_7H_5N_3O_6$

Density = 1.6800 g/cc   Mixture TMD = 1.7997 g/cc   **% TMD = 93.3466**

The C-J condition:

The pressure	=	22.48 GPa
The volume	=	0.455 cc/g
The density	=	2.196 g/cc
The energy	=	2.64 kJ/cc explosive
The temperature	=	3680 K
The shock velocity	=	7.548 mm/us
The particle velocity	=	1.773 mm/us
The speed of sound	=	5.776 mm/us
Gamma	=	3.258

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	-4.73	98	74	63	52	108
4.10	-5.74	99	74	65	54	104
6.50	-6.17	99	74	65	55	101
10.00	-6.45	99	74	66	56	98
20.00	-6.80	99	74	67	57	95
40.00	-7.05	99	74	67	58	91
80.00	-7.26	98	74	68	59	88
160.00	-7.42					

Freezing occurred at T = 1800.0 K and relative V = 1.983
The mechanical energy of detonation = -7.665 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -7.665 kJ/cc

JWL Fit results:
E0 = -7.960 kJ/cc
A = 803.02 GPa, B = 8.15 GPa, C = 1.28 GPa
R[1] = 4.98, R[2] = 1.11, omega = 0.37
RMS fitting error = 0.89 %

C.4 MCX-8001 - BKWS Product Library

C.4.1 TMD 1.8087 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	52.00	66.76	49.24	-24140	130.07	1.91	$C_2H_2N_4O_3$
TNT	36.00	26.47	39.37	-15057	227.13	1.65	$C_7H_5N_3O_6$
HMX	12.00	6.77	11.39	17866	296.17	1.91	$C_4H_8N_8O_8$

Density = 1.8087 g/cc Mixture TMD = 1.8087 g/cc **% TMD = 100.0000**

The C-J condition:

The pressure = 26.59 GPa
The volume = 0.426 cc/g
The density = 2.348 g/cc
The energy = 3.06 kJ/cc explosive
The temperature = 3599 K
The shock velocity = 7.998 mm/us
The particle velocity = 1.838 mm/us
The speed of sound = 6.160 mm/us
Gamma = 3.351

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	-0.95					
2.20	-5.33	110	84	71	59	122
4.10	-6.40	110	83	72	61	116
6.50	-6.84	110	82	73	61	112
10.00	-7.13	109	82	73	62	109
20.00	-7.49	109	82	73	63	104
40.00	-7.75	108	82	74	64	100
80.00	-7.95	108	81	74	64	97
160.00	-8.12					

Freezing occurred at T = 1800.0 K and relative V = 1.868
The mechanical energy of detonation = -8.366 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -8.366 kJ/cc

JWL Fit results:

E0 = -8.672 kJ/cc
A = 1017.22 GPa, B = 9.10 GPa, C = 1.31 GPa
R[1] = 5.00, R[2] = 1.11. omega = 0.37
RMS fitting error = 0.90 %

C.4.2 Density 1.79 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	52.00	66.76	49.24	-24140	130.07	1.91	$C_2H_2N_4O_3$
TNT	36.00	26.47	39.37	-15057	227.13	1.65	$C_7H_5N_3O_6$
HMX	12.00	6.77	11.39	17866	296.17	1.91	$C_4H_8N_8O_8$

Density = 1.7900 g/cc Mixture TMD = 1.8087 g/cc % **TMD = 98.9687**

The C-J condition:

The pressure	=	25.92 GPa
The volume	=	0.430 cc/g
The density	=	2.326 g/cc
The energy	=	2.99 kJ/cc explosive
The temperature	=	3608 K
The shock velocity	=	7.927 mm/us
The particle velocity	=	1.827 mm/us
The speed of sound	=	6.100 mm/us
Gamma	=	3.339

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	-0.93					
2.20	-5.23	108	82	70	58	120
4.10	-6.29	108	81	71	60	114
6.50	-6.73	108	81	71	60	110
10.00	-7.02	108	81	72	61	107
20.00	-7.37	107	80	72	62	103
40.00	-7.63	107	80	73	63	99
80.00	-7.84	106	80	73	63	95
160.00	-8.00					

Freezing occurred at T = 1800.0 K and relative V = 1.884
The mechanical energy of detonation = -8.254 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -8.254 kJ/cc

JWL Fit results:
E0 = -8.558 kJ/cc
A = 982.77 GPa, B = 8.93 GPa, C = 1.30 GPa
R[1] = 5.00, R[2] = 1.11. omega = 0.37
RMS fitting error = 0.90 %

C.4.3 Density 1.78 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	52.00	66.76	49.24	-24140	130.07	1.91	$C_2H_2N_4O_3$
TNT	36.00	26.47	39.37	-15057	227.13	1.65	$C_7H_5N_3O_6$
HMX	12.00	6.77	11.39	17866	296.17	1.91	$C_4H_8N_8O_8$

Density = 1.7800 g/cc Mixture TMD = 1.8087 g/cc **% TMD = 98.4158**

The C-J condition:

```
The pressure          =          25.56 GPa
The volume            =          0.432 cc/g
The density           =          2.314 g/cc
The energy            =           2.95 kJ/cc explosive
The temperature       =           3613 K
The shock velocity    =          7.888 mm/us
The particle velocity =          1.821 mm/us
The speed of sound    =          6.068 mm/us
Gamma                 =          3.333
```

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	-0.92					
2.20	-5.18	107	82	69	57	119
4.10	-6.23	107	81	70	59	113
6.50	-6.67	107	80	71	60	109
10.00	-6.96	107	80	71	61	106
20.00	-7.31	106	80	72	62	102
40.00	-7.57	106	80	72	62	98
80.00	-7.78	106	80	73	63	94
160.00	-7.94					

```
Freezing occurred at T =     1800.0 K and relative V =   1.892
The mechanical energy of detonation =     -8.194 kJ/cc
The thermal energy of detonation    =     -0.000 kJ/cc
The total energy of detonation      =     -8.194 kJ/cc
```

JWL Fit results:

```
E0   =       -8.585 kJ/cc
A    =       943.66 GPa, B    =      8.52 GPa, C     =         1.12 GPa
R[1] =         4.94,     R[2] =      1.06,     omega =         0.33
RMS fitting error =   1.11 %
```

C.4.4 Density 1.77 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	52.00	66.76	49.24	-24140	130.07	1.91	$C_2H_2N_4O_3$
TNT	36.00	26.47	39.37	-15057	227.13	1.65	$C_7H_5N_3O_6$
HMX	12.00	6.77	11.39	17866	296.17	1.91	$C_4H_8N_8O_8$

Density = 1.7700 g/cc   Mixture TMD = 1.8087 g/cc   **% TMD = 97.8629**

The C-J condition:

The pressure	=	25.21 GPa
The volume	=	0.434 cc/g
The density	=	2.302 g/cc
The energy	=	2.91 kJ/cc explosive
The temperature	=	3618 K
The shock velocity	=	7.850 mm/us
The particle velocity	=	1.814 mm/us
The speed of sound	=	6.036 mm/us
Gamma	=	3.326

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	-0.91					
2.20	-5.13	106	81	69	57	118
4.10	-6.17	106	80	70	58	112
6.50	-6.61	106	80	70	59	108
10.00	-6.90	106	79	71	60	105
20.00	-7.25	106	79	71	61	101
40.00	-7.51	105	79	72	62	97
80.00	-7.72	105	79	72	62	94
160.00	-7.88					

Freezing occurred at T = 1800.0 K and relative V = 1.900
The mechanical energy of detonation = -8.134 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -8.134 kJ/cc

JWL Fit results:

E0 = -8.524 kJ/cc
A = 925.49 GPa, B = 8.43 GPa, C = 1.12 GPa
R[1] = 4.94, R[2] = 1.06. omega = 0.33
RMS fitting error = 1.11 %

C.4.5 Density 1.76 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	52.00	66.76	49.24	-24140	130.07	1.91	$C_2H_2N_4O_3$
TNT	36.00	26.47	39.37	-15057	227.13	1.65	$C_7H_5N_3O_6$
HMX	12.00	6.77	11.39	17866	296.17	1.91	$C_4H_8N_8O_8$

Density = 1.7600 g/cc   Mixture TMD = 1.8087 g/cc   **% TMD = 97.3100**

The C-J condition:

```
The pressure          =          24.87 GPa
The volume            =          0.437 cc/g
The density           =          2.290 g/cc
The energy            =           2.88 kJ/cc explosive
The temperature       =           3622 K
The shock velocity    =          7.812 mm/us
The particle velocity =          1.808 mm/us
The speed of sound    =          6.004 mm/us
Gamma                 =          3.320
```

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	-0.90					
2.20	-5.07	105	80	68	56	116
4.10	-6.11	105	79	69	58	111
6.50	-6.55	105	79	70	59	107
10.00	-6.84	105	79	70	60	104
20.00	-7.19	105	79	71	61	100
40.00	-7.45	104	78	71	61	96
80.00	-7.66	104	78	71	62	93
160.00	-7.82					

```
Freezing occurred at T =     1800.0 K and relative V =   1.908
The mechanical energy of detonation =     -8.074 kJ/cc
The thermal energy of detonation    =     -0.000 kJ/cc
The total energy of detonation      =     -8.074 kJ/cc
```

JWL Fit results:

```
E0   =       -8.463 kJ/cc
A    =       907.48 GPa, B    =      8.33 GPa, C     =         1.12 GPa
R[1] =         4.94,     R[2] =      1.06,     omega =         0.33
RMS fitting error =   1.11 %
```

C.4.6 Density 1.75 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	52.00	66.76	49.24	-24140	130.07	1.91	$C_2H_2N_4O_3$
TNT	36.00	26.47	39.37	-15057	227.13	1.65	$C_7H_5N_3O_6$
HMX	12.00	6.77	11.39	17866	296.17	1.91	$C_4H_8N_8O_8$

Density = 1.7500 g/cc Mixture TMD = 1.8087 g/cc **% TMD = 96.7571**

The C-J condition:

The pressure	=	24.52 GPa
The volume	=	0.439 cc/g
The density	=	2.278 g/cc
The energy	=	2.84 kJ/cc explosive
The temperature	=	3627 K
The shock velocity	=	7.774 mm/us
The particle velocity	=	1.802 mm/us
The speed of sound	=	5.972 mm/us
Gamma	=	3.313

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	-0.89					
2.20	-5.02	104	79	67	55	115
4.10	-6.06	104	78	68	57	110
6.50	-6.49	104	78	69	58	106
10.00	-6.79	104	78	69	59	103
20.00	-7.13	104	78	70	60	99
40.00	-7.39	103	78	71	61	96
80.00	-7.60	103	78	71	62	92
160.00	-7.76					

Freezing occurred at T = 1800.0 K and relative V = 1.916
The mechanical energy of detonation = -8.015 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -8.015 kJ/cc

JWL Fit results:
E0 = -8.315 kJ/cc
A = 912.84 GPa, B = 8.59 GPa, C = 1.29 GPa
R[1] = 4.99, R[2] = 1.11, omega = 0.36
RMS fitting error = 0.89 %