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Gunnar Ove Nevstad

FFI Forsvarets forskningsinstitutt

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Gunnar Ove Nevstad

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Approved by

Ivar Sollien	Research Manager
Jon E. Skjervold	Director

English summary

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

The quality of the casted test items of MCX-6100 with regard to density and homogeneity has been varied. X-ray of a cylindrical charge of CH 6027/14 shows lower density in the top than in the bottom. Bubbles and pores are observed in the upper part of the charge, even though vacuum was applied during the casting. The casting process has therefore potential for improvement.

MCX-6100 CH 6027/14 has been characterized with regards to critical diameter, detonation velocity and detonation pressure. Sedimentation was studied by analyses of content in the longitudinal direction of the fillings.

Critical diameter for MCX-6100 CH 6027/14 is measured to 18.5 mm and 19.0 mm for two tested conical charges.

The average detonation velocity of a cylindrical test item with density 1.74 g/cm3 was measured to 7420 m/s. This is 250 m/s below the theoretical calculated value with Cheetah 2.0 at TMD. For a conical charge the detonation velocity between charge diameter 27 mm and 20 mm was measured to 5435 m/s.

Detonation pressure measured by Plate Dent gave a detonation pressure of 207 kbar. As for the detonation velocity this result is below the theoretical value calculated by Cheetah 2.0.
For the different contents of MCX-6100 due to sedimentation theoretical calculations with Cheetah 2.0 and TEMPER 2.2.2 have been performed. These results show the influence of sedimentation on performance and fragmentation. Porosity has been calculated from the differences in densities between measured and calculated values. The results show highest porosity in the top of the fillings and lowest in the bottom part.

Sammendrag

Komposisjonen MCX-6100 er utviklet og produsert av Chemring Nobel AS. Dette er en smeltestøpt komposisjon som primært anvendes som sprengstoff i 120 mm og 155 mm granater. Vi har karakterisert komposisjonen ut fra dens potensiale for bruk i denne type ammunisjon. MCX-6100 har DNAN som bindemiddel. Faststoffet er en blanding av NTO og RDX. Nominell sammensetning for MCX-6100 er 32/53/15 (DNAN/NTO/RDX). Ved å bruke DNAN som bindemiddel kan alle anlegg for fylling av TNT eller TNT-baserte komposisjoner også benyttes til fylling av MCX-6100.

Denne rapporten omhandler hvordan MCX-6100 CH 6027/14 er karakterisert med hensyn på kritisk diameter, detonasjonshastighet og detonasjonstrykk. Sedimentering er studert ved analyse av sammensetning i lengderetningen av støpte enheter. For de ulike sammensetningene er det utført teoretiske beregninger av virkning ved bruk av Cheetah 2.0 og for fragmentering med TEMPER 2.2.

Røntgen av en sylindrisk ladning viser lavere tetthet i toppen enn i bunnen. Innholdet av luftbobler/porer er i stor grad konsentrert til den øvre halvdel av ladningen. Benyttet prosedyre for støping har derfor potensiale for forbedringer, selv om vakuum var benyttet.
Kritisk diameter for MCX-6100 CH 6027/14 er bestemt til 18,5 mm og 19 mm i to tester av to koner.

Detonasjonshastigheten er målt for en sylindrisk ladning og for en konisk ladning med største diameter 30 mm. Detonasjonshastigheten for sylindrisk ladning med tetthet 1,74 g/cm3 er målt til 7420 m/s. Målt detonasjonshastighet er 250 m/s lavere enn teoretisk beregnet med Cheetah 2.0. For det koniske testlegemet er detonasjonshastighet mellom ladningsdiameter 27 og 20 mm målt til 5435 m/s.

Detonasjonstrykket er målt til 207 kbar ved bruk av Plate Dent-test. Det eksperimentelt målte detonasjonstrykket er som detonasjonshastigheten, noe lavere enn teoretisk beregnet med Cheetah 2.0.

For de ulike sammensetningene til MCX-6100 har effekten av sedimentering vært studert ved hjelp av teoretiske beregninger med Cheetah 2.0 og TEMPER. Disse beregningene viser at porøsiteten er høyest i toppen og lavest i bunnen av fyllingene.

Contents

Abbreviations

BAMO	3,3-Bis-azidomethyl oxetane
DNAN	2,4-dinitroanisole
DSTO	**D**efence **S**cience and **T**echnology **O**rganization
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	**I**nsensitive **M**unitions
IMX-104	NTO/DNAN/RDX (53/31.7/15.3) (3)
MCX	**M**elt **C**ast **E**xplosive
MCX-6100	NTO/DNAN/RDX (53/32/15)
NTO	3-Nitro-1,2,4 Triazol 5-one
RDX	Hexogen/1,3,5 -trinitro-1,3,5-triazacyclohexane
TEMPER	**T**oolbox of **E**ngineering **M**odels for **P**rediction of **E**xplosive **R**eactions
TMD	**T**heoretical **M**aximum **D**ensity
TNT	2,4,6-trinitrotoluene
WP	Work Package

1 Introduction

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

In order to broaden the number of different compositions included in the generic fragmentation testing in 40 mm shell in WP 4000, Norway included 4 melt-pour compositions. These compositions are all of interest for Norway as main filler preferentially for large calibre munitions. Two compositions have TNT and two have DNAN as binder, while the filler is NTO/RDX or NTO/HMX. These compositions have, in addition to the fragmentation performance, been characterized for important properties as detonation velocity, detonation pressure and critical diameter (1). In addition shock sensitivity for the two compositions containing RDX have been determined (2, 3).

Dinitroanisole (DNAN) is a key IM melt-phase ingredient that is currently featured in several IM melt-pour formulations developed by the U.S. Army and the Australian DSTO (4-8). Current interest in DNAN has occurred primarily due to its ability to provide a less sensitive melt cast medium than TNT, and allows the development of less sensitive melt-cast formulations. Since DNAN is processed essentially in the same way as TNT, analogous explosive formulations can easily be transitioned. In addition, DNAN can be demilitarized the same way as TNT using the same recover / re-use hardware. Currently DNAN-based formulations are tailored to have TNT or Comp B performance, while having decreased sensitivity.

In this report MCX-6100 CH 6027/14 has been characterized with regards to critical diameter, detonation velocity and detonation pressure. MCX-6100 contains DNAN as binder and the filler is NTO/RDX. Nominal content of MCX-6100 is 53/32/15 (NTO/DNAN/ RDX). This composition has NTO/RDX content in the same range as the DNAN based US composition IMX-104 (53/31.7/15.3) (8) and the TNT based Chemring MCX-6002 composition (2). In (1) we performed a similar characterization with CH 6079/13, but we were not satisfied with the quality of the test items. The casting of the test items is critical to obtain wanted quality regarding density and sedimentation. DNAN as TNT has a large change in volume going from liquid to solid, app. 10-15 volume %.

Critical diameter has been determined by use of conical charges and witness plates (9). In addition two conical charges were fitted with ionization pins to measure detonation velocity (10) as function of charge diameter. The detonation velocity was measured for a cylindrical charge in a plastic tube by use of 5 ionization pins. Detonation pressure was measured with Plate Dent Test (11, 12). A similar tube as used for measuring detonation velocity was used to study the sedimentation by analysing the content and measuring the density in the top, middle and bottom part of the charge. For these different compositions of MCX-6100 theoretical performance and density were calculated with Cheetah 2.0 (13). Calculations of fragmentation were performed with TEMPER 2.2.2 (14)

2 Experiments

2.1 Casting

The casting was performed with vacuum by Chemring Nobel AS.

2.2 Quality

The visual inspection of the charge showed some empty space in the top and a curved surface at the bottom. In order to measure detonation pressure a plane bottom of the charge is required. To correct these errors, both the top and the bottom were cut manually by a saw blade. The final surface finish was done with sandpaper. Figure 2.1 shows pictures of the charge, the top and bottom before modification, and Figure 2.2 shows pictures of the top and bottom of the test item after modification.

Figure 2.1 Casted charge to the left, the top in the middle and the bottom to the right.

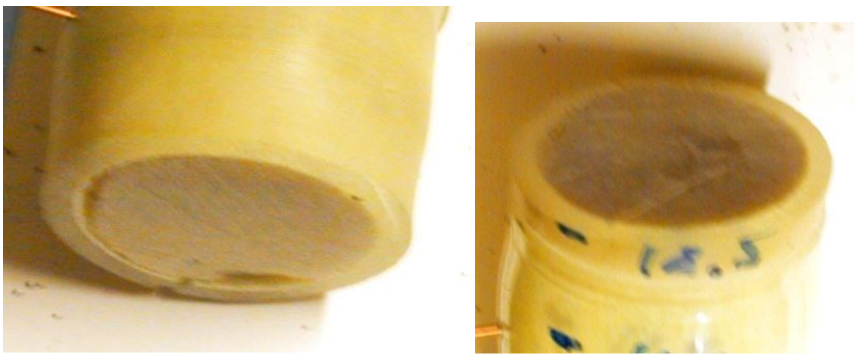

Figure 2.2 Pictures of the top and bottom of the charge after modification; left bottom – right top.

2.3 X-ray

The quality of the test charge was checked by X-ray. The investigation was performed with a 320kV apparatus at Nammo Raufoss. The X-ray picture is shown in Figure 2.3, showing in addition to what could be seen visually, some areas with low density in the upper third part of the charge.

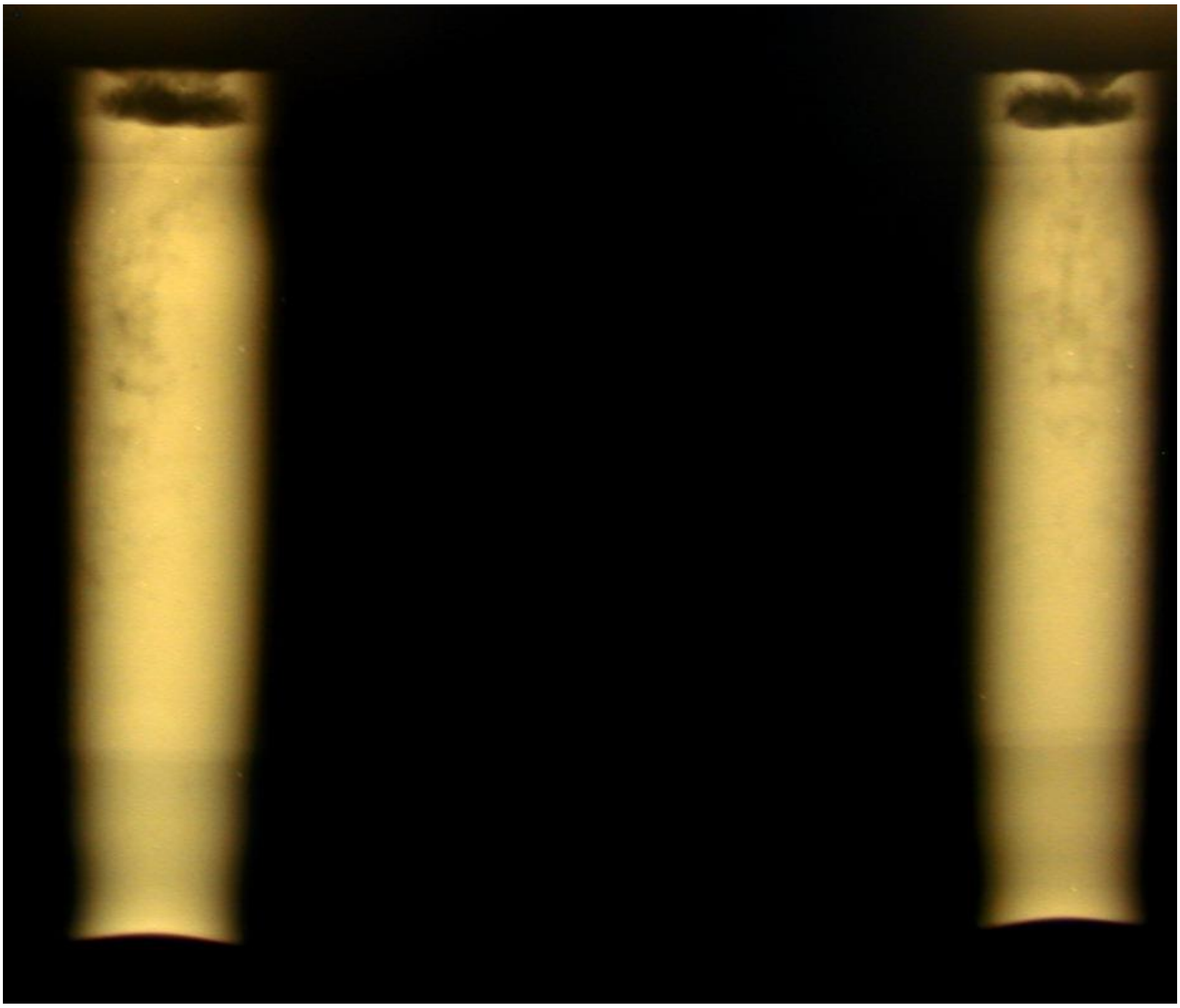

Figure 2.3 X-ray picture of the test item, to the left at V=0^o and to the right at 90^o.

2.4 Detonation velocity

Detonation velocity was measured by use of 5 ionization pins positioned as shown in Figure 2.4, with a distance of 30 mm between each pin. The ionization pins and setup for registration on the storage oscilloscope is described in (10). The oscilloscope used to collect the results for this test was a GW Instek GDS-3352, Digital Storage Oscilloscope, and 350 MHz 5 GS/s adjusted to DC. All other settings/conditions used for the firing are summarized in Table 2.1.

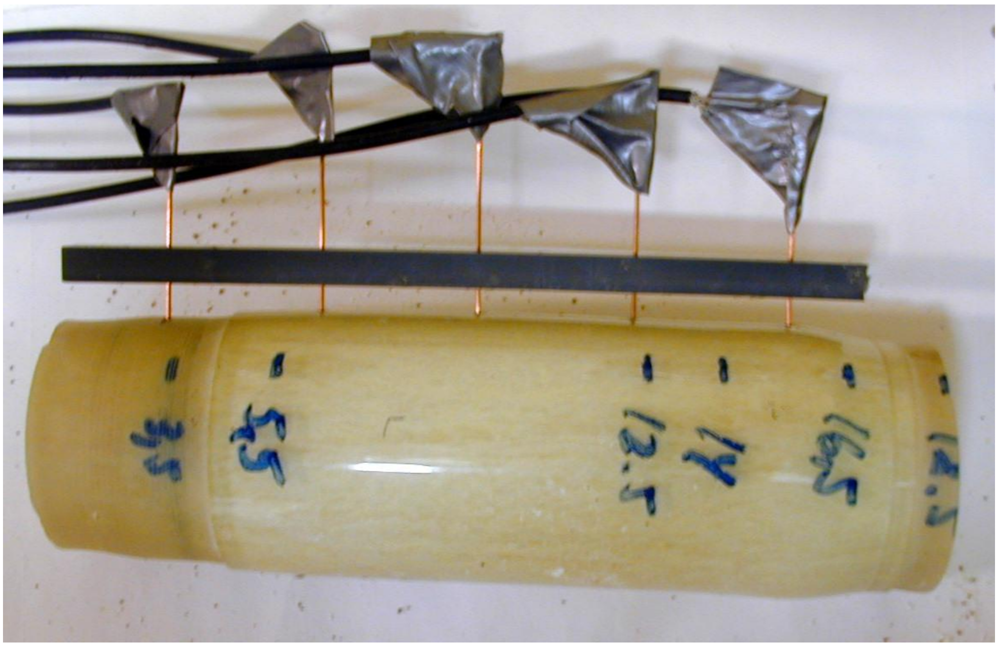

Figure 2.4 The picture shows the positions of the ionization pins.

Memory Length	25000
Trigger Level	-2.02V
Source	CH1
Probe	1.000E+00
Vertical Units	V
Vertical Scale	2.000E+00
Vertical Position	5.920E+00
Horizontal Units	S
Horizontal Scale	1.000E-05
Horizontal Position	3.970E-05
Horizontal Mode	Main
Sampling Period	4.000E-09
Firmware	V1.09
Time	06.03.2015 14:56
Mode	Detail
Waveform Data	

Table 2.1 The scope settings used to collect the results for the firing.

Figure 2.5 The picture shows the length of the pins that go into the charge/cast.

2.5 Critical diameter

Two conical charges were casted in 270 mm long polypropylene moulds with inner diameter 30 mm in the top and 3 mm in the bottom. Figure 2.6 shows the charges in the polypropylene moulds after solidification. The casts were released from the moulds and the top of the charges modified. The critical diameter was determined by two different methods: detonation velocity measurements with ionization pins and by use of witness plate.

2.5.1 Conical charge test No 1

Conical charge cast 40/14 CH 6027/14 had after modification of the top, a diameter of 29.4 mm. The diameter of the bottom was 10.55 mm. Total length of the released charge was 196 mm with a weight of 98.16 g.

These numbers give a filling density of 1.55 g/cm^3. Figure 2.6 shows that the cast contains some bubbles explaining the low density. Figure 2.7 shows that in the transfer between the two halves of the mould, there are several bubbles probably due to leakage of melted composition during the solidification.

Figure 2.7 shows the test item after fitting with 4 ionization pins, added a HWC booster and assembled on the witness plate. The ionization pins were positioned at a charge diameter of 27 mm, 24 mm, 22 mm and the last at 20 mm.

The sampling conditions for the test firing are summarized in Table 2.2.

Figure 2.6 Picture of conical charge cast 60/14 to the left and cast 40/14 to the right together with a picture of the divided mould of cast 40/14.

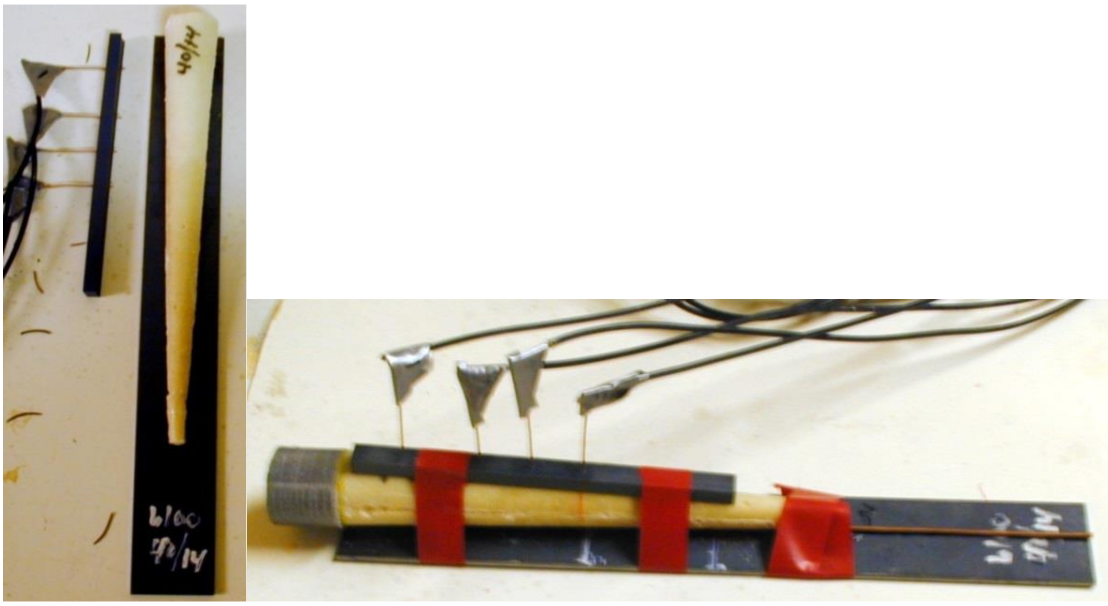

Figure 2.7 Pictures of the test item before and after introduction of the ionization pins.

2.5.2 Conical charge test No 2

Conical charge cast 60/14 of CH 6027/14 was the second one to be tested. After released from the mould and modification of the top and bottom, the remaining had a length of 204 mm.

Figure 2.8| Pictures of conical charge 60/14 before assembled on the witness plate.

	Conical charge Cast 40/14	**Conical charge Cast 60/14**
Memory Length	25000	25000
Trigger Level	-2.48V	-2.48V
Source	CH1	CH1
Probe	1.000E+00	1.000E+00
Vertical Units	V	V
Vertical Scale	2.000E+00	2.000E+00
Vertical Position	3.760E+00	3.760E+00
Horizontal Units	S	S
Horizontal Scale	1.000E-05	1.000E-05
Horizontal Position	4.000E-05	4.000E-05
Horizontal Mode	Main	Main
Sampling Period	4.000E-09	4.000E-09
Firmware	V1.09	V1.09
Time	05-Nov-14 14:52:03	05-Nov-14 15:05:01
Mode	Detail	Detail
Waveform Data		

Table 2.2 Firing conditions for the conical charges cast 40/14 and cast 60/14 of MCX-6100 CH 6027/14.

At the top the charge had a diameter of 29.3 mm and the bottom 9.55 mm. The weight of the charge was measured to 96.76 g. This gives an overall density of 1.53 g/cm^3 for the filling. For conical charge 40/14 this is a moderate density. The ionization pins were positioned at a charge diameter of 27 mm, 24 mm, 22 mm and the last at 20 mm. The sampling conditions for the test firing are summarized in Table 2.2.

2.6 Pressure

Detonation pressure for the cylindrical charge was measured by use of the Plate Dent Test (11, 12). A bolt steel plate of ST-52 quality with diameter 160 mm and height 70 mm was used as witness plate. Figure 2.9 shows how the Dent depth was measured with a micrometer screw, a steel ring and a steel ball.

Figure 2.9 Picture of the tool used to measure the Dent depth.

2.7 Initiation

All firings reported in this document were performed with a booster of HWC and a detonator No 8. Appendix A gives the certificate of the applied HWC explosive. The boosters were pressed using a tool with diameter 31.5 mm, with 10 tons pressure and a dwell time of 60 seconds. The sample weight was 35 g. For the cylindrical charge one 80 g donor pellet for Intermediate Scale Gap Test was used as booster. This pellet had a density of 1.60 g/cm^3 and a diameter of 40 mm.

2.8 Theoretical calculations

All calculations of detonation velocity and pressure reported in this document were performed with Cheetah 2.0 (13). Calculations of fragmentation were performed with TEMPER 2.2.2 (14).

3 RESULTS

3.1 Detonation velocity

The test items used in the study was a cylindrical charge in a plastic tube equipped with 5 ionization pins 30 mm between each and with total measuring distance of 120 mm. The setup for the measuring of detonation velocity and pressure is shown in Figure 3.1. The obtained registration of the firing on the storage oscilloscope is shown in Figure 3.2.

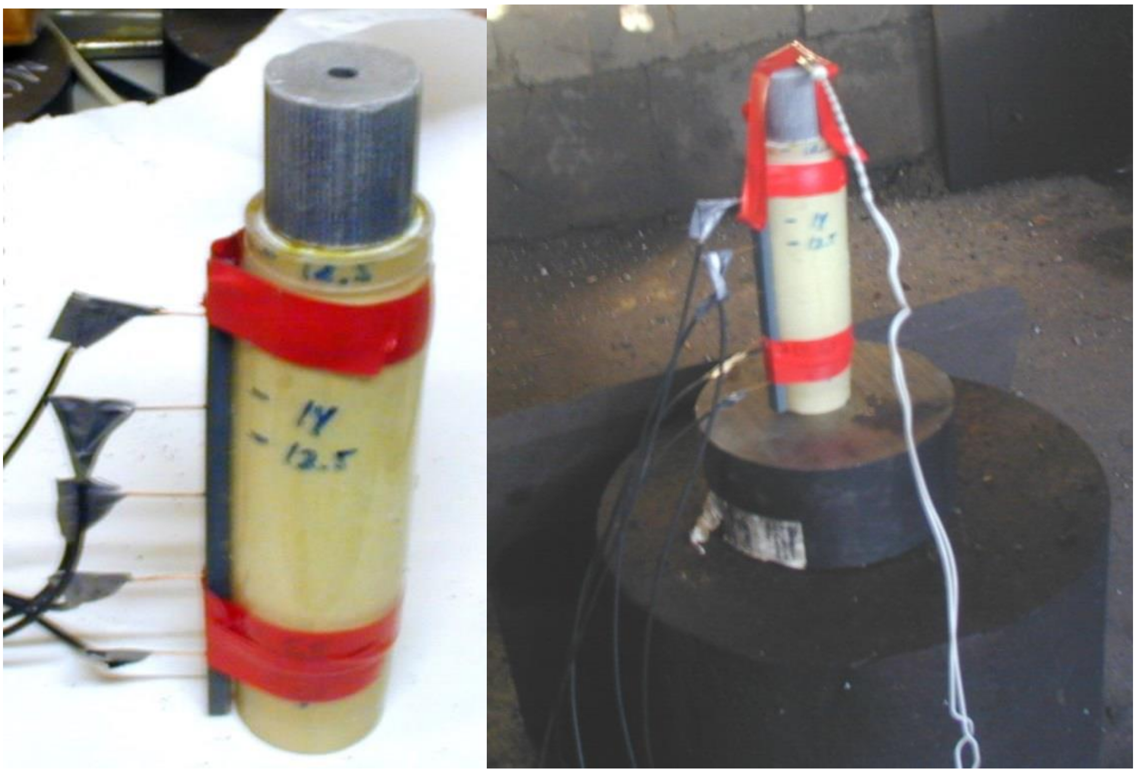

Figure 3.1 Pictures of the test charge before firing and test setup to the right.

Figure 3.2 The pictures show the storage oscilloscope with registration after firing.

The registration by the storage oscilloscope was transferred to a PC (with Excel software) using a storage pin. Figure 3.3 shows that all 5 ionization pins gave registration. The Figure shows arrival times of the detonation front in addition to the distance between each ionization pin.

Table 3.1 summarizes the information in Figure 3.3 and gives the calculated detonation velocity between each ionization pin and the overall detonation velocity. The detonation velocity is shown to be stable with an average of 7420 m/s. This is slightly higher than observed in earlier determinations (1) and thereby closer to the Cheetah calculated velocity for nominal content of 7671 m/s at TMD. Nexter (15) has measured the detonation velocity for a charge with diameter 50 mm to 7314 m/s. The density of the Nexter charge was 1.75 g/cm^3, while our charge had a density of 1.74 g/cm^3. The last cylindrical charge was tested in the plastic mould. The effect of this confinement is unknown, but it may well give increase in detonation velocity.

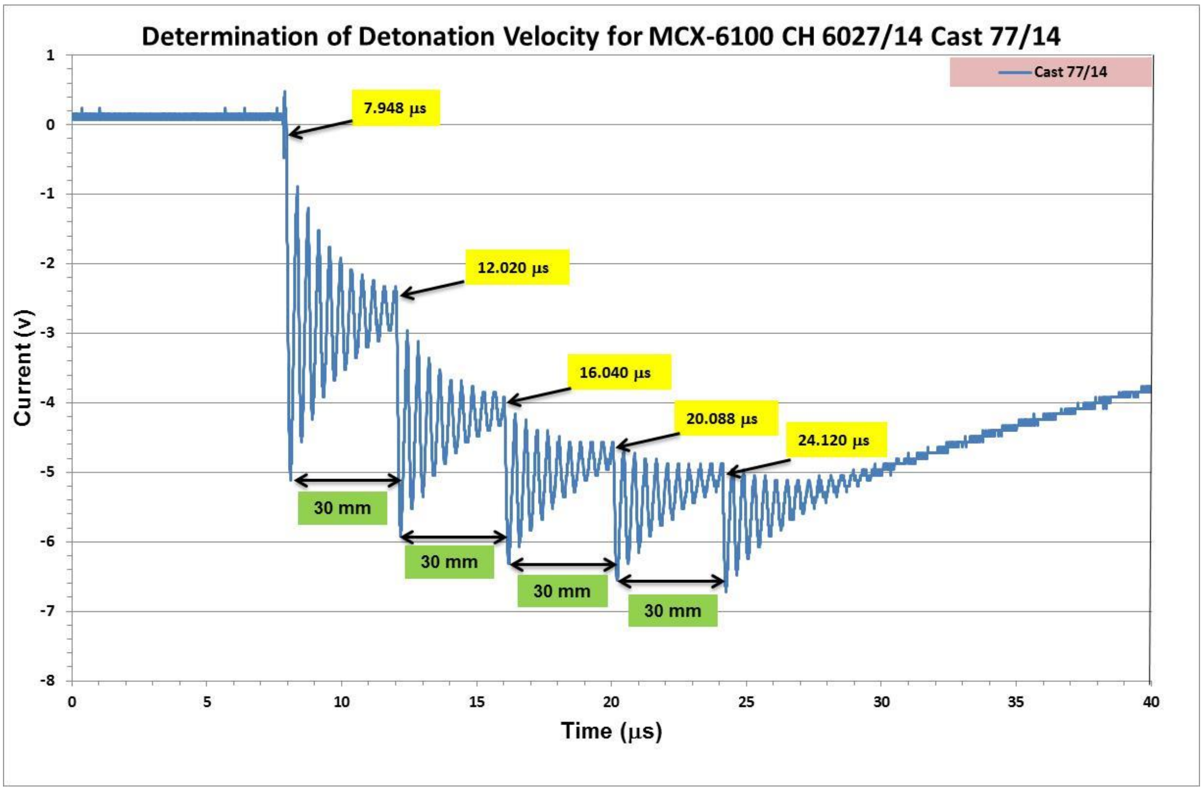

Figure 3.3 Arrival times of the detonation front for the 5 different ionization pins.

Pin No	Arrival time (µs)	Distance from pin X to Pin X-1 (mm)	Time between pin No X and X-1 (µs)	Detonation velocity (m/s)
	Cast 77/14 MCX-6100 CH 6027/14			
1	7.948			
2	12.020	30	4.072	7367
3	16.040	30	4.020	7463
4	20.088	30	4.048	7411
5	24.120	30	4.032	7440
1-5		120	16.172	**7420**

Table 3.1 A summary of the results from the measurement of the detonation velocity for MCX 6100 CH 6027/14 cast 77/14.

3.2 Pressure

To measure the detonation pressure a 70 mm thick steel cylinder witness plate of ST-52 quality was used. The setup is shown in Figure 3.1, while pictures of the witness plate after firing is shown in Figure 3.4.

Figure 3.4 Pictures of the Dent plate after firing.

Table 3.2 summarizes the firing result and properties. The obtained detonation pressure of 207 kbar is higher than for similar charges tested in (1). However the obtained pressure is still below the Cheetah calculated detonation pressure for nominal content of MCX-6100 at TMD of 245.4 kbar.

Firing No	Charge Diameter (mm)	Charge density (g/cm^3)	Dent (mm)	Detonation Pressure (kbar)
1	37.0	1.74?	5.31	**207**
Average				**207**

Table 3.2 Measured detonation pressures for MCX 6100 CH 6027/14 cast 77/14.

3.3 Critical diameter

Two conical charges of MCX-6100 CH 6027/14 were received from Chemring Nobel AS. We decided to perform testing with 4 ionization pins in each charge to determine the detonation velocity as function of charge diameter in addition to witness plates.

3.3.1 Test item No 1 - cast 40/14 CH 6027/14

Figure 3.5 shows the test item after assembling. The ionization pins were positioned at a charge diameter of 27 mm, 24 mm, 22 mm and 20 mm. Setup of the test is shown in Figure 3.6. Figure 3.6 gives in addition the obtained registration at the storage oscilloscope. The oscilloscope shows registration for all 4 ionization pins. The witness plate from the firing is shown in Figure 3.10.

Figure 3.5 Picture of the assembled test item on the witness plate.

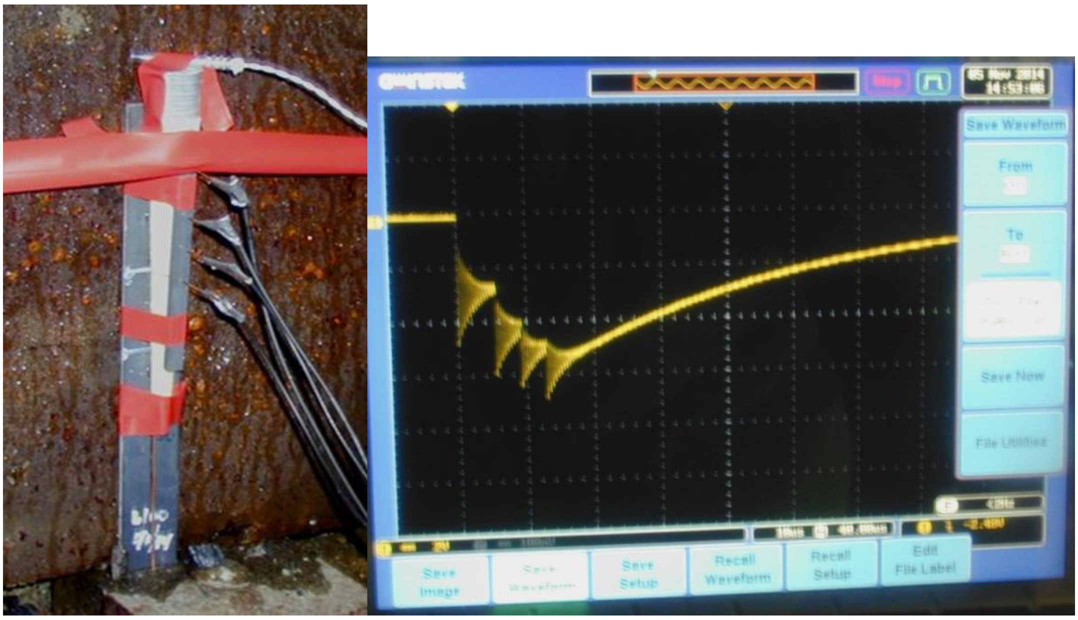

Figure 3.6 Test setup to measure the critical diameter for conical charge cast 40/14 with MCX-6100 CH 6027/14, and obtained registration on the storage oscilloscope after firing.

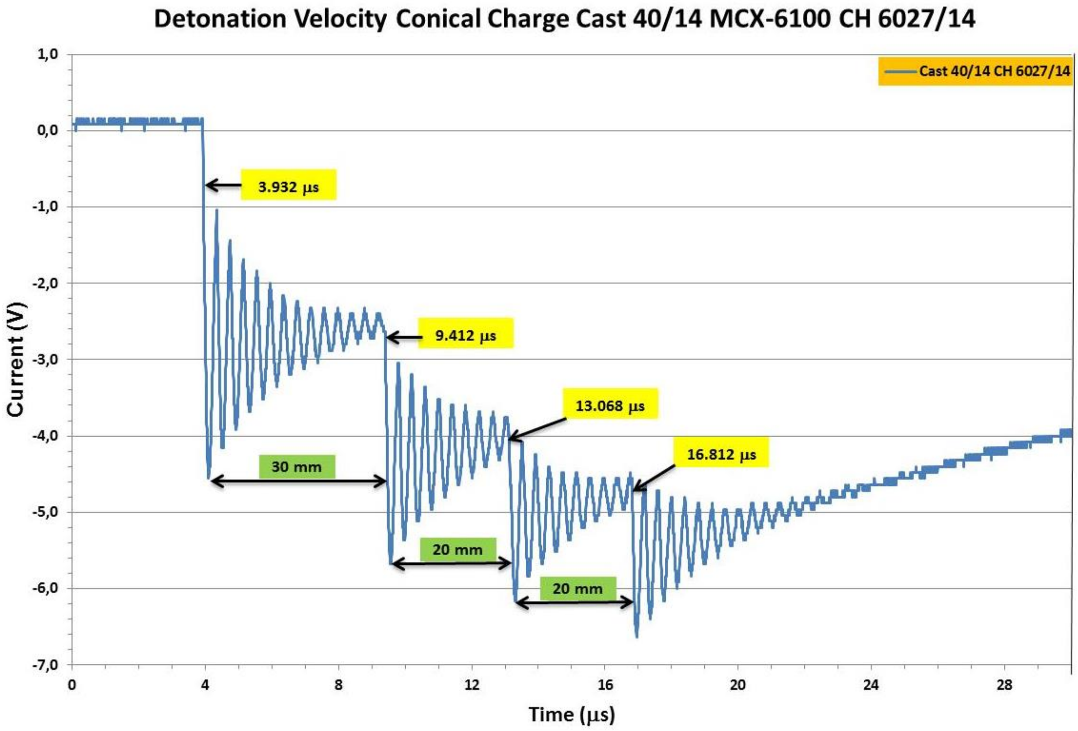

Figure 3.7 Arrival times of the detonation front at the different ionization pins.

Pin No	Charge diameter (mm)	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)
	Conical charge cast 40/14 containing MCX-6100 CH 6027/14				
1	27	3.932			
2	24	9.412	5.48	30	**5474**
3	22	13.068	3.656	20	**5470**
4	20	16.812	3.744	20	**5342**
1-4			12.88	70	**5435**

Table 3.3 Detonation velocity in different parts of test item 40/14.

Table 3.3 summarizes the results for the detonation velocity in cone 40/14. We have registration on all 4 ionization pins, one more than expected. The detonation velocity is approximately equal from a diameter of 27 mm to a diameter of 20 mm. A moderate reduction in the detonation velocity, 132 m/s, is observed between charge diameters of 20-22 mm compared to a diameter of 24-27 mm, but the difference is in order of the accuracy of the method. The overall low detonation velocity is most probably explained by the low density of the cast rather than the charge diameter.

3.3.2 Test item No 2 - cast 60/14 CH 6027/14

The second conical test charge with MCX-6100 CH 6027/14 we tested was cast 60/14. Figure 3.8 shows the conical test item after being assembled on the witness plate ready to be tested. It contained 4 ionization pins positioned at a charge diameter of 27, 24, 22 and 20 mm. Setup for the firing is shown in Figure 3.9 together with what we obtained of registration on the storage oscilloscope.

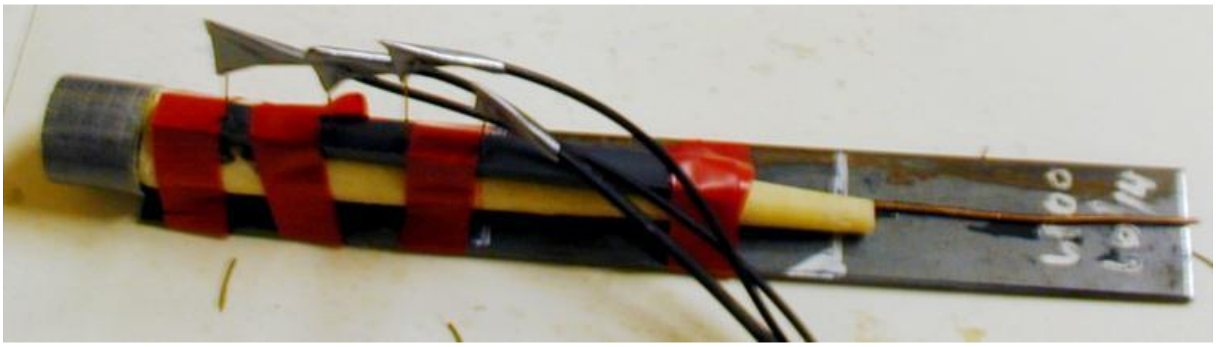

Figure 3.8 Assembled test item cast 60/14 for critical diameter determination for MCX-6100 CH 6027/14.

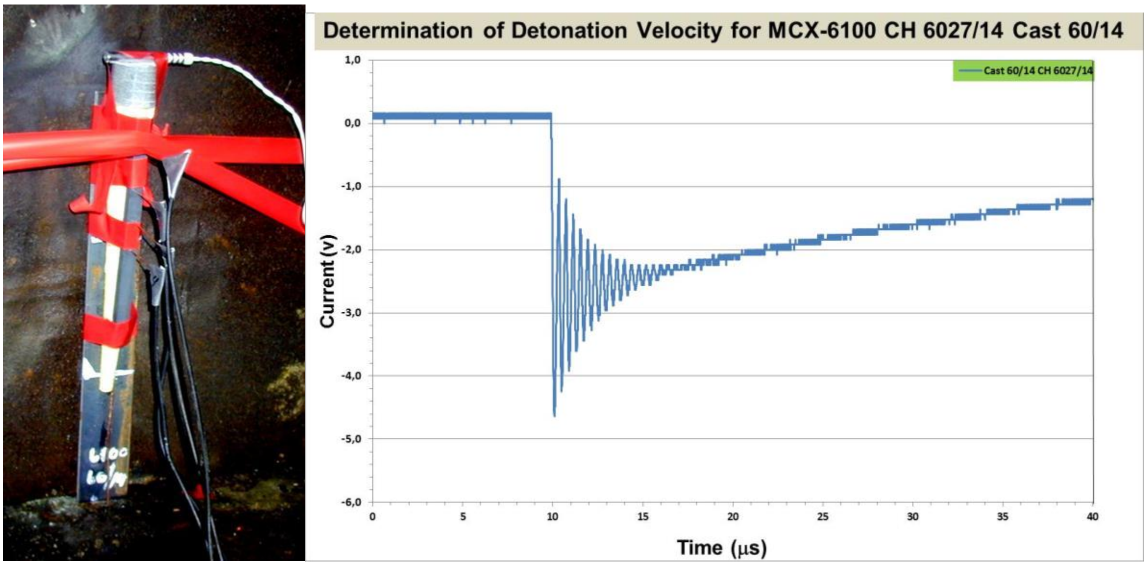

Figure 3.9 To the left setup of the test item cast 60/14. To the right obtained registration on the storage oscilloscope after firing.

Figure 3.9 shows that registration was obtained only for one ionization pin. Therefore we were unable to determine the detonation velocity. However, the detonation occurred as expected, and we obtained results on the witness plate as shown in Figure 3.10.

3.3.3 Comparing of test results

Figure 3.10 shows pictures of the two witness plates after firing of the two MCX-6100 CH 6027/14 conical charges. For both firings unreacted parts of the explosive were recovered. The recovered explosive is shown in Figure 3.10. Interpretation of the witness plates for conical charge 40/14 gave a critical diameter of 18.5 mm and for the conical charge 60/14 a critical diameter of 19 mm. The results for conical charge cast 40/14 explain the unexpected registration on the ionization pin positioned at a charge diameter of 20 mm.

In (1) results from testing of 5 conical charges with MCX-6100 were reported. They had an average critical diameter of 19.1 ± 1.4 mm. The 4 most similar results gave 19.7 ± 0.8 mm. The results of MCX-6100 CH 6027/14 with a critical diameter of 18.5 and 19 mm are in the same range.

Figure 3.10 Pictures of the witness plates for MCX-6100 CH 6027/14 cast 40/14 and cast 60/14 included recovered unreacted explosive.

3.4 Sedimentation

Two similar cylindrical charges filled with MCX-6100 CH 6027/14 were casted under vacuum. One charge was used to measure detonation velocity and pressure, while the second was used to

Position	RDX (Wt. %)	NTO (Wt. %)	DNAN (Wt. %)	Measured density (g/cm^3)	Porosity (%)
Top	13.5	57.2	29.3	1.74	1.9
Middle	14.3	55.5	30.2	1.74	1.1
Bottom	14.2	56.5	29.3	1.76	0.7
Nominal	15	53	32		

Table 3.4 Analysed content and density of the cylindrical test charge.

study sedimentation. The second charge was cut into different sections and samples from the top, middle and bottom analysed with regard to content and density. Table 3.4 summarizes the obtained results. In general the content shows lower portions of RDX and DNAN and higher portion of NTO than expected from the nominal content.

A 155 mm filled shell was earlier cut in longitudinal direction. Density and content were determined for samples from the top, middle and bottom of the filling. The results are shown in Table 3.5. These results are different compared with the results for the cylindrical charge. For the samples from the shell the content of the substance with highest density (NTO), is significant higher in the bottom of the shell. The 155 mm filling had in addition higher porosity than the filling for the cylindrical charge (Table 3.5). However, for both fillings the highest porosity is observed in the top.

Position	RDX (Wt. %)	NTO (Wt. %)	DNAN (Wt. %)	Measured density (g/cm^3)	Porosity (%)
Top	15.9	52.7	31.3	1.72	2.52
Middle	14.8	54.7	30.6	1.73	2.18
Bottom	14.7	57.1	28.2	1.75	1.56
Nominal	15	53	32		

Table 3.5 Analysed contents and densities with calculated porosities for the MCX-6100 filling in a 155 mm shell.

3.5 Performance and fragmentation variations due to sedimentation

Obtained differences in contents in the longitudinal direction of the cylindrical charge have been used to calculate performance at TMD and at the measured density by use of Cheetah 2.0 (13). The results are summarized in Table 3.6. The summary printouts for these calculations are given in appendix C. Calculations of the porosity of the filling, sound velocity, C_o and slope S of D=f (u) have been performed with NEWGATES V.1-10 (16) and reported in (17, 18). Gurney velocity and Mott constant are calculated as described in (19). The number of fragments produced by a 30 kg 155 mm shell filled with different MCX-6100 compositions has been calculated with an Excel-sheet in TEMPER 2.2 (14) for different envelope thicknesses and is reported (18).

Table 3.6 summarizes properties for performing TEMPER simulations with MCX-6100 CH 6027/14. Table 3.7 gives similar results for MCX CH 6079/13 (1). The better performance with respect to detonation velocity and pressure increase the number of fragments from 3015 to 3626 and from 3880 to 4665 for an Envelop thickness of 15 and 13 mm respectively or 20.3 %. Both these results are significantly lower than 5402 and 6951 expected with nominal content and theoretical calculated properties. A lot of comparisons for the fragmentation ability due to changes in properties of the fillings can be done. However, the main conclusion is that sedimentation and porosity of a MCX-6100 filling as for other melt cast fillings with 2 or more ingredients will have significant influence on the fragmentation ability of munition warheads.

Cheetah Calculations for MCX-6100 with BKWC Product Library Cylindrical Charge								Experimentally measured velocity pressure density
	Nominal	Top		Middle		Bottom		
TMD (g/cm^3)	1.7629	1.7746		1.7704		1.7739		
Measured density (g/cm^3)			1.74		1.74		1.76	**1.74**
DNAN (%)	32	29.3		30.2		29.3		
NTO (%)	53	57.2		55.5		56.5		
RDX (%)	15	13.5		14.3		14.2		
Porosity (%)		1.9		1.1		0.7		
Pressure (GPa)	24.54	25.03	23.76	24.88	23.77	25.06	24.54	**20.7**
Velocity (m/s)	7671	7736	7614	7716	7609	7740	7691	**7420**
Gamma	3.226	3.243	3.246	3.236	3.239	3.240	3.242	**3.228**
Gurney Cooper (m/s)	2583	2605	2564	2598	2562	2606	2590	**2498**
Mott constant (kg$^{1/2}$m$^{-7/6}$)	3.105	3.033	3.227	3.055	3.225	3.029	3.105	**3.790**
C_o (m/s)	2922	2.911	2.625	2.915	2.662	2.911	2.794	**2730**
S	1.60	1.61	1.79	1.60	1.77	1.61	1.69	**1.72**
	Number of fragments							
Envelop thickness 15 mm	**5402**	**5661**	**5001**	**5581**	**5008**	**5676**	**5402**	**3626**
Envelop thickness 14 mm	**6102**	**6395**	**5650**	**6304**	**5657**	**6413**	**6102**	**4096**
Envelop thickness 13 mm	**6951**	**7285**	**6435**	**7181**	**6443**	**7304**	**6951**	**4665**

Table 3.6 Theoretical and experimental properties of MCX-6100 cylindrical charge compositions and fragmentations performance for 155 mm shell of these.

Cheetah Calculations for MCX-6100 with BKWC Product Library Divided 155 mm Shell								Experimentally measured velocity pressure density
	Nominal	Top		Middle		Bottom		
TMD (g/cm^3)	1.7629	1.7646		1.7685		1.7777		
Measured density (g/cm^3)			1.72		1.73		1.75	**1.71**
Pressure (GPa)	24.54	24.72	23.11	24.83	23.43	25.31	24.28	**19.1**
Velocity (m/s)	7671	7693	7537	7708	7573	7772	7674	**7268**
Gamma	3.226	3.225	3.228	3.233	3.235	3.243	3.245	
Gurney Cooper (m/s)	2583	2590	2538	2595	2550	2617	2584	**2447**
Mott constant (kg$^{1/2}$m$^{-7/6}$)	3.105	3.079	3.334	3.062	3.280	2.993	3.145	**4.156**
C_o (m/s)	2922	2920	2557	2916	2598	2906	2676	
S	1.60	1.60	1.83	160	1.80	1.62	1.77	
	Number of fragments							
Envelop thickness 15 mm	**5402**	**5493**	**4686**	**5555**	**4841**	**5814**	**5265**	**3015**
Envelop thickness 14 mm	**6102**	**6206**	**5293**	**6275**	**5468**	**6567**	**5948**	**3406**
Envelop thickness 13 mm	**6951**	**7069**	**6029**	**7147**	**6229**	**7481**	**6775**	**3880**

Table 3.7 Theoretical and experimental properties of MCX-6100 155 mm filling compositions and their fragmentation performance in155 mm shell.

4 Summary

The basis for this study is variable quality of the MCX-6100 fillings with regard to filling density and homogeneity. X-ray of a cylindrical charge shows lower density in the top than in the bottom of the charge. Bubbles are observed in the upper part of the charge. Even though vacuum have been applied during casting, the applied casting has proved an indisputable potential for improvement.

MCX-6100 CH 6027/14 has been characterized with regards to critical diameter, detonation velocity and detonation pressure. Sedimentation was studied by determination of density and content in the longitudinal direction of a cylindrical charge.

Critical diameter for MCX-6100 CH 6027/14 was measured to be 18.5 mm and 19.0 mm for two tested conical charges.

The average detonation velocity for a cylindrical charge with density 1.74 g/cm^3 was measured to be 7420m/s. This result is 250 m/s below the theoretical value calculated with Cheetah 2.0 at TMD. For a conical charge, between the charge diameters of 27 mm and 20 mm, the detonation velocity was measured to be 5435 m/s.

Detonation pressure measured by Plate Dent gave a detonation pressure of 207 kbar. As for the detonation velocity, this is below the theoretical value calculated by Cheetah 2.0

Theoretical calculations of performance and fragmentation have been performed with Cheetah 2.0 and TEMPER on nominal content and on analysed contents of MCX-6100 due to sedimentation. The fragmentation ability of a 155 mm shell is significantly affected by sedimentation and porosity of the MCX-6100 fillings.

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Appendix A Certificate of Plate 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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OVAKO IMATRA

Inspection certificate EN 10204 3.2 DNV 1/ 2

26.9.2013 357406 DNV HEL 13-2183

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

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

CAST ANALYSIS

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

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

CHARPY V2/-20 C (J)

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

TENSILE TEST FROM 1/3 RADIUS

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

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

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

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

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

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

OVAKO IMATRA

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

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

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

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

```
The bundle labels are stamped

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

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

Ovako Imatra Oy Ab
Matti Happonen
Authorized Inspector
Quality Control Laboratory

For certification/MSA
Ilpo Lehtola
Station Manager,Helsinki Office
```

DET NORSKE VERITAS ESTABLISHED 1864

MSA R-1447

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

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

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

Appendix B Control report HWC

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

KONTROLLRAPPORT B
etter EN 10204 - 3.1

Chemring Nobel

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

Analyseresultater for loten

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

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

Kvalitetssjef

Chemring Nobel AS
High Energy Materials
Manager QA

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

Appendix C Cheetah printouts for MCX-6100

C.1 Nominal content MCX-6100 and TMD 1.7629 g/cm^3

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

The composition:
Name        % wt.   % mol   % vol    Heat of     Mol.    TMD
                                    formation    wt.     (g/cc)
                                    (cal/mol)
rdx         15.00   10.61   14.64    16496    222.13     1.81 c3h6n6o6
nto         53.00   64.02   48.92   -24140    130.07     1.91 c2h2n4o3
dnan24      32.00   25.37   36.44   -44455    198.13     1.55 c7h6n2o5

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

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

Cylinder runs:                % of standards
  V/V0      Energy     TATB      PETN      HMX     CL-20    TRITON
 (rel.)    (kJ/cc)  1.83g/cc 1.76g/cc 1.89g/cc 2.04g/cc 1.70g/cc
   1.00     -0.86
   2.20     -4.73      98        75        63        52       109
   4.10     -5.69      98        74        64        54       103
   6.50     -6.11      98        74        65        55       100
  10.00     -6.39      98        74        65        56        97
  20.00     -6.73      98        73        66        57        94
  40.00     -6.99      98        74        67        58        90
  80.00     -7.19      98        74        67        58        87
 160.00     -7.36

Freezing occurred at T =     1800.0 K and relative V =   1.744
The mechanical energy of detonation =      -7.616 kJ/cc
The thermal energy of detonation    =      -0.000 kJ/cc
The total energy of detonation      =      -7.616 kJ/cc

JWL Fit results:
E0   =       -7.951 kJ/cc
A    =       815.26 GPa, B    =      7.43 GPa, C     =         1.22 GPa
R[1] =         4.86,     R[2] =      1.10,     omega =         0.35
RMS fitting error =   0.66 %
```

C.2 Top of cylindrical charge

C.2.1 At TMD 1.7746 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	57.23	67.84	53.17	-24140	130.07	1.91	c2h2n4o3
dnan24	29.31	22.81	33.60	-44455	198.13	1.55	c7h6n2o5
rdx	13.46	9.34	13.23	16496	222.13	1.81	c3h6n6o6

Density = 1.7746 g/cc   Mixture TMD = 1.7746 g/cc   % TMD = 100.0000

The C-J condition:
The pressure = 25.03 GPa
The volume = 0.431 cc/g
The density = 2.322 g/cc
The energy = 2.95 kJ/cc explosive
The temperature = 3392 K
The shock velocity = 7.736 mm/us
The particle velocity = 1.823 mm/us
The speed of sound = 5.913 mm/us
Gamma = 3.243

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	-4.79	99	75	64	53	110
4.10	-5.75	99	74	65	54	104
6.50	-6.16	99	74	65	55	101
10.00	-6.44	99	74	66	56	98
20.00	-6.77	99	74	66	57	94
40.00	-7.02	98	74	67	58	91
80.00	-7.23	98	74	67	59	88
160.00	-7.39					

Freezing occurred at T = 1800.0 K and relative V = 1.712
The mechanical energy of detonation = -7.622 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -7.622 kJ/cc

JWL Fit results:
E0 = -7.957 kJ/cc
A = 843.33 GPa, B = 7.52 GPa, C = 1.22 GPa
R[1] = 4.87, R[2] = 1.10, omega = 0.35
RMS fitting error = 0.66 %

C.2.2 At measured 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	57.23	67.84	53.17	-24140	130.07	1.91	c2h2n4o3
dnan24	29.31	22.81	33.60	-44455	198.13	1.55	c7h6n2o5
rdx	13.46	9.34	13.23	16496	222.13	1.81	c3h6n6o6

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

Density = 1.7400 g/cc   Mixture TMD = 1.7746 g/cc   % TMD = 98.0501

The C-J condition:
The pressure = 23.76 GPa
The volume = 0.439 cc/g
The density = 2.276 g/cc
The energy = 2.80 kJ/cc explosive
The temperature = 3402 K
The shock velocity = 7.614 mm/us

```
The particle velocity =          1.793 mm/us
The speed of sound    =          5.821 mm/us
Gamma                 =          3.246

Cylinder runs:             % of standards
  V/V0     Energy    TATB     PETN      HMX    CL-20   TRITON
 (rel.)   (kJ/cc)  1.83g/cc 1.76g/cc 1.89g/cc 2.04g/cc 1.70g/cc
   1.00    -0.84
   2.20    -4.61      95       73       62       51      106
   4.10    -5.56      96       72       63       53      101
   6.50    -5.96      96       72       63       54       98
  10.00    -6.24      96       72       64       54       95
  20.00    -6.57      96       72       64       55       92
  40.00    -6.82      95       72       65       56       88
  80.00    -7.02      95       72       66       57       85
 160.00    -7.19

Freezing occurred at T =     1800.0 K and relative V =   1.737
The mechanical energy of detonation =     -7.421 kJ/cc
The thermal energy of detonation    =     -0.000 kJ/cc
The total energy of detonation      =     -7.421 kJ/cc

JWL Fit results:
E0   =       -7.752 kJ/cc
A    =       806.14 GPa, B    =      7.24 GPa,  C     =         1.21 GPa
R[1] =         4.88,     R[2] =      1.10,      omega =         0.35
RMS fitting error =   0.67 %
```

C.3 Middle of cylindrical charge

C.3.1 At TMD 1.7704 g/cm^3

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

The composition:
Name      % wt.   % mol  % vol    Heat of     Mol.   TMD
                                 formation    wt.    (g/cc)
                                 (cal/mol)
dnan24     30.20  23.69  34.54   -44455   198.13     1.55 c7h6n2o5
nto        55.50  66.31  51.44   -24140   130.07     1.91 c2h2n4o3
rdx        14.30  10.00  14.02    16496   222.13     1.81 c3h6n6o6

Density  =  1.7704 g/cc   Mixture TMD =  1.7704 g/cc   % TMD = 100.0000

The C-J condition:
The pressure          =          24.88 GPa
The volume            =          0.432 cc/g
The density           =          2.317 g/cc
The energy            =           2.94 kJ/cc explosive
The temperature       =           3400 K
The shock velocity    =          7.716 mm/us
The particle velocity =          1.821 mm/us
The speed of sound    =          5.895 mm/us
Gamma                 =          3.236

Cylinder runs:             % of standards
  V/V0     Energy    TATB     PETN      HMX    CL-20   TRITON
 (rel.)   (kJ/cc)  1.83g/cc 1.76g/cc 1.89g/cc 2.04g/cc 1.70g/cc
   1.00    -0.87
   2.20    -4.78      98       75       64       53      110
   4.10    -5.74      99       74       65       54      104
   6.50    -6.15      99       74       65       55      101
```

```
  10.00    -6.43      99        74        66        56        98
  20.00    -6.76      98        74        66        57        94
  40.00    -7.02      98        74        67        58        91
  80.00    -7.22      98        74        67        58        88
 160.00    -7.39

Freezing occurred at T =     1800.0 K and relative V =   1.726
The mechanical energy of detonation =     -7.629 kJ/cc
The thermal energy of detonation    =     -0.000 kJ/cc
The total energy of detonation      =     -7.629 kJ/cc

JWL Fit results:
E0   =       -8.042 kJ/cc
A    =       836.83 GPa, B    =      7.55 GPa, C     =         1.07 GPa
R[1] =         4.86,     R[2] =      1.07,     omega =         0.32
RMS fitting error =   0.87 %
```

C.3.2 At measured 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     Mol.   TMD
                                  formation    wt.    (g/cc)
                                  (cal/mol)
dnan24     30.20  23.69  34.54   -44455   198.13     1.55 c7h6n2o5
nto        55.50  66.31  51.44   -24140   130.07     1.91 c2h2n4o3
rdx        14.30  10.00  14.02    16496   222.13     1.81 c3h6n6o6

Density  =  1.7400 g/cc   Mixture TMD =  1.7704 g/cc   % TMD = 98.2834

The C-J condition:
The pressure          =          23.77 GPa
The volume            =          0.439 cc/g
The density           =          2.277 g/cc
The energy            =           2.80 kJ/cc explosive
The temperature       =           3409 K
The shock velocity    =          7.609 mm/us
The particle velocity =          1.795 mm/us
The speed of sound    =          5.814 mm/us
Gamma                 =          3.239

Cylinder runs:             % of standards
  V/V0     Energy    TATB     PETN      HMX    CL-20   TRITON
 (rel.)   (kJ/cc)  1.83g/cc 1.76g/cc 1.89g/cc 2.04g/cc 1.70g/cc
   1.00    -0.84
   2.20    -4.62      95        73        62        51       106
   4.10    -5.57      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    -6.84      96        72        65        56        89
  80.00    -7.05      96        72        66        57        85
 160.00    -7.21

Freezing occurred at T =     1800.0 K and relative V =   1.748
The mechanical energy of detonation =     -7.452 kJ/cc
The thermal energy of detonation    =     -0.000 kJ/cc
The total energy of detonation      =     -7.452 kJ/cc
```

```
JWL Fit results:
E0   =       -7.783 kJ/cc
A    =       800.93 GPa, B    =      7.25 GPa, C     =         1.21 GPa
R[1] =         4.87,     R[2] =      1.10,     omega =         0.35
RMS fitting error =   0.67 %
```

C.4 Bottom of cylindrical charge

C.4.1 At TMD 1.7739 g/cm^3

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

The composition:
Name      % wt.   % mol  % vol    Heat of     Mol.   TMD
                                formation     wt.    (g/cc)
                                (cal/mol)
nto        56.50  67.22  52.48   -24140   130.07     1.91 c2h2n4o3
dnan24     29.30  22.88  33.58   -44455   198.13     1.55 c7h6n2o5
rdx        14.20   9.89  13.95    16496   222.13     1.81 c3h6n6o6

Density  =  1.7739 g/cc   Mixture TMD =  1.7739 g/cc   % TMD = 100.0000

The C-J condition:
The pressure          =          25.06 GPa
The volume            =          0.431 cc/g
The density           =          2.321 g/cc
The energy            =           2.96 kJ/cc explosive
The temperature       =           3399 K
The shock velocity    =          7.740 mm/us
The particle velocity =          1.825 mm/us
The speed of sound    =          5.915 mm/us
Gamma                 =          3.240

Cylinder runs:             % of standards
  V/V0     Energy    TATB      PETN      HMX    CL-20   TRITON
 (rel.)   (kJ/cc)  1.83g/cc 1.76g/cc 1.89g/cc 2.04g/cc 1.70g/cc
   1.00    -0.88
   2.20    -4.80      99        76       64       53      110
   4.10    -5.76      99        75       65       55      104
   6.50    -6.17      99        74       66       55      101
  10.00    -6.45      99        74       66       56       98
  20.00    -6.79      99        74       67       57       95
  40.00    -7.04      98        74       67       58       91
  80.00    -7.24      98        74       68       59       88
 160.00    -7.41

Freezing occurred at T =     1800.0 K and relative V =   1.719
The mechanical energy of detonation =     -7.641 kJ/cc
The thermal energy of detonation    =     -0.000 kJ/cc
The total energy of detonation      =     -7.641 kJ/cc

JWL Fit results:
E0   =       -8.054 kJ/cc
A    =       845.53 GPa, B    =      7.59 GPa, C     =         1.07 GPa
R[1] =         4.86,     R[2] =      1.07,     omega =         0.32
RMS fitting error =   0.87 %
```

C.4.2 At measured 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     Mol.   TMD
                                  formation     wt.    (g/cc)
                                  (cal/mol)
nto         56.50  67.22  52.48   -24140   130.07     1.91 c2h2n4o3
dnan24      29.30  22.88  33.58   -44455   198.13     1.55 c7h6n2o5
rdx         14.20   9.89  13.95    16496   222.13     1.81 c3h6n6o6

Density  =  1.7600 g/cc   Mixture TMD =  1.7739 g/cc   % TMD = 99.2138

The C-J condition:
The pressure          =          24.54 GPa
The volume            =          0.434 cc/g
The density           =          2.303 g/cc
The energy            =           2.89 kJ/cc explosive
The temperature       =           3403 K
The shock velocity    =          7.691 mm/us
The particle velocity =          1.813 mm/us
The speed of sound    =          5.878 mm/us
Gamma                 =          3.242

Cylinder runs:              % of standards
  V/V0     Energy    TATB     PETN      HMX    CL-20   TRITON
 (rel.)   (kJ/cc)  1.83g/cc 1.76g/cc 1.89g/cc 2.04g/cc 1.70g/cc
   1.00    -0.86
   2.20    -4.73      98       74       63       52      108
   4.10    -5.68      98       74       64       54      103
   6.50    -6.09      98       73       65       55      100
  10.00    -6.37      98       73       65       55       97
  20.00    -6.71      98       73       66       56       94
  40.00    -6.96      97       73       66       57       90
  80.00    -7.16      97       73       67       58       87
 160.00    -7.32

Freezing occurred at T =     1800.0 K and relative V =   1.729
The mechanical energy of detonation =     -7.560 kJ/cc
The thermal energy of detonation    =     -0.000 kJ/cc
The total energy of detonation      =     -7.560 kJ/cc

JWL Fit results:
E0   =       -7.971 kJ/cc
A    =       830.54 GPa, B    =     7.47 GPa, C     =         1.07 GPa
R[1] =         4.87,     R[2] =     1.07,     omega =         0.32
RMS fitting error =   0.87 %
```

C.5 Top of 155 mm shell

C.5.1 At TMD 1.7646 g/cm^3

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

The composition:
Name       % wt.   % mol  % vol    Heat of     Mol.   TMD
                                  formation     wt.    (g/cc)
                                  (cal/mol)
nto         52.70  63.79  48.69   -24140   130.07     1.91 c2h2n4o3
```

```
dnan24      31.30  24.87  35.68   -44455   198.13     1.55 c7h6n2o5
rdx         16.00  11.34  15.63    16496   222.13     1.81 c3h6n6o6
Product library title: bkwc

Density  =  1.7646 g/cc   Mixture TMD =  1.7646 g/cc   % TMD = 100.0000

The C-J condition:
The pressure          =         24.73 GPa
The volume            =         0.433 cc/g
The density           =         2.312 g/cc
The energy            =          2.93 kJ/cc explosive
The temperature       =          3415 K
The shock velocity    =         7.694 mm/us
The particle velocity =         1.821 mm/us
The speed of sound    =         5.873 mm/us
Gamma                 =         3.225

Cylinder runs:               % of standards
  V/V0     Energy    TATB      PETN      HMX    CL-20   TRITON
 (rel.)    (kJ/cc)  1.83g/cc 1.76g/cc 1.89g/cc 2.04g/cc 1.70g/cc
   1.00    -0.87
   2.20    -4.77      98        75        64       53      109
   4.10    -5.73      99        74        65       54      104
   6.50    -6.15      99        74        65       55      101
  10.00    -6.43      99        74        66       56       98
  20.00    -6.77      99        74        66       57       94
  40.00    -7.03      98        74        67       58       91
  80.00    -7.23      98        74        68       59       88
 160.00    -7.40

Freezing occurred at T =     1800.0 K and relative V =   1.748
The mechanical energy of detonation =     -7.653 kJ/cc
The thermal energy of detonation    =     -0.000 kJ/cc
The total energy of detonation      =     -7.653 kJ/cc

JWL Fit results:
E0   =       -8.068 kJ/cc
A    =       823.34 GPa, B    =      7.54 GPa, C     =         1.08 GPa
R[1] =         4.86,     R[2] =      1.06,     omega =         0.32
RMS fitting error =   0.87 %
```

C.5.2 At measured 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     Mol.    TMD
                                  formation     wt.    (g/cc)
                                  (cal/mol)
nto         52.70  63.79  48.69   -24140   130.07     1.91 c2h2n4o3
dnan24      31.30  24.87  35.68   -44455   198.13     1.55 c7h6n2o5
rdx         16.00  11.34  15.63    16496   222.13     1.81 c3h6n6o6
Product library title: bkwc

Density  =  1.7200 g/cc   Mixture TMD =  1.7646 g/cc   % TMD = 97.4735

The C-J condition:
The pressure          =         23.12 GPa
The volume            =         0.444 cc/g
The density           =         2.253 g/cc
The energy            =          2.73 kJ/cc explosive
The temperature       =          3428 K
The shock velocity    =         7.538 mm/us
The particle velocity =         1.783 mm/us
The speed of sound    =         5.755 mm/us
Gamma                 =         3.228
```

```
Cylinder runs:              % of standards
  V/V0     Energy    TATB      PETN      HMX    CL-20   TRITON
 (rel.)   (kJ/cc)  1.83g/cc 1.76g/cc 1.89g/cc 2.04g/cc 1.70g/cc
   1.00    -0.82
   2.20    -4.54      94        72        61       50      104
   4.10    -5.49      94        71        62       52       99
   6.50    -5.89      95        71        63       53       96
  10.00    -6.17      95        71        63       54       94
  20.00    -6.51      95        71        64       55       91
  40.00    -6.77      95        71        65       56       88
  80.00    -6.97      95        71        65       56       85
 160.00    -7.14

Freezing occurred at T =     1800.0 K and relative V =   1.780
The mechanical energy of detonation =     -7.392 kJ/cc
The thermal energy of detonation    =     -0.000 kJ/cc
The total energy of detonation      =     -7.392 kJ/cc

JWL Fit results:
E0   =       -7.799 kJ/cc
A    =       776.41 GPa, B    =      7.18 GPa, C     =         1.07 GPa
R[1] =         4.87,     R[2] =      1.06,     omega =         0.32
RMS fitting error =   0.88 %
```

C.6 Middle of 155 mm shell

C.6.1 At TMD 1.7685 g/cm^3

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

The composition:
Name      % wt.   % mol  % vol    Heat of     Mol.   TMD
                                 formation    wt.    (g/cc)
                                 (cal/mol)
dnan24     30.57  24.07  34.92    -44455   198.13     1.55 c7h6n2o5
nto        54.65  65.55  50.60    -24140   130.07     1.91 c2h2n4o3
rdx        14.79  10.38  14.48     16496   222.13     1.81 c3h6n6o6

Density  =  1.7685 g/cc   Mixture TMD =  1.7685 g/cc   % TMD = 100.0000

The C-J condition:
The pressure           =          24.83 GPa
The volume             =          0.432 cc/g
The density            =          2.316 g/cc
The energy             =           2.93 kJ/cc explosive
The temperature        =           3404 K
The shock velocity     =          7.708 mm/us
The particle velocity =           1.821 mm/us
The speed of sound     =          5.887 mm/us
Gamma                  =          3.233

Cylinder runs:              % of standards
  V/V0     Energy    TATB      PETN      HMX    CL-20   TRITON
 (rel.)   (kJ/cc)  1.83g/cc 1.76g/cc 1.89g/cc 2.04g/cc 1.70g/cc
   1.00    -0.87
   2.20    -4.77      98        75        64       53      109
   4.10    -5.73      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    -6.76      98        74        66       57       94
  40.00    -7.02      98        74        67       58       91
  80.00    -7.22      98        74        67       58       88
 160.00    -7.39

Freezing occurred at T =     1800.0 K and relative V =   1.732
The mechanical energy of detonation =     -7.635 kJ/cc
The thermal energy of detonation    =     -0.000 kJ/cc
The total energy of detonation      =     -7.635 kJ/cc
```

```
JWL Fit results:
E0   =       -7.969 kJ/cc
A    =       828.77 GPa, B    =      7.49 GPa , C     =         1.22 GPa
R[1] =         4.86,     R[2] =      1.10,      omega =         0.35
RMS fitting error =   0.66 %
```

C.6.2 At measured 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     Mol.   TMD
                                  formation    wt.    (g/cc)
                                  (cal/mol)
dnan24     30.57  24.07  34.92    -44455   198.13     1.55 c7h6n2o5
nto        54.65  65.55  50.60    -24140   130.07     1.91 c2h2n4o3
rdx        14.79  10.38  14.48     16496   222.13     1.81 c3h6n6o6

Density  =  1.7300 g/cc   Mixture TMD =  1.7685 g/cc   % TMD = 97.8221

The C-J condition:
The pressure          =          23.43 GPa
The volume            =          0.442 cc/g
The density           =          2.265 g/cc
The energy            =           2.77 kJ/cc explosive
The temperature       =           3415 K
The shock velocity    =          7.573 mm/us
The particle velocity =          1.788 mm/us
The speed of sound    =          5.785 mm/us
Gamma                 =          3.235

Cylinder runs:              % of standards
  V/V0     Energy    TATB     PETN      HMX    CL-20   TRITON
 (rel.)   (kJ/cc)  1.83g/cc 1.76g/cc 1.89g/cc 2.04g/cc 1.70g/cc
   1.00    -0.83
   2.20    -4.58      94       72       61       51      105
   4.10    -5.52      95       72       62       52      100
   6.50    -5.93      95       71       63       53       97
  10.00    -6.21      95       71       63       54       95
  20.00    -6.54      95       71       64       55       91
  40.00    -6.80      95       72       65       56       88
  80.00    -7.00      95       72       65       57       85
 160.00    -7.16

Freezing occurred at T =     1800.0 K and relative V =   1.760
The mechanical energy of detonation =     -7.410 kJ/cc
The thermal energy of detonation    =     -0.000 kJ/cc
The total energy of detonation      =     -7.410 kJ/cc

JWL Fit results:
E0   =       -7.741 kJ/cc
A    =       787.96 GPa, B    =      7.18 GPa, C     =         1.21 GPa
R[1] =         4.87,     R[2] =      1.10,     omega =         0.35
RMS fitting error =   0.67 %
```

C.7 Bottom of 155 mm shell

C.7.1 At TMD1.7777 g/cm^3

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

The composition:
Name       % wt.   % mol  % vol    Heat of     Mol.   TMD
                                  formation    wt.    (g/cc)
```

```
                                 (cal/mol)
dnan24      28.20  21.98  32.38   -44455   198.13     1.55 c7h6n2o5
nto         57.10  67.80  53.15   -24140   130.07     1.91 c2h2n4o3
rdx         14.70  10.22  14.47    16496   222.13     1.81 c3h6n6o6

Density  =  1.7777 g/cc   Mixture TMD =  1.7777 g/cc   % TMD = 100.0000

The C-J condition:
The pressure          =          25.31 GPa
The volume            =          0.430 cc/g
The density           =          2.326 g/cc
The energy            =           2.98 kJ/cc explosive
The temperature       =           3404 K
The shock velocity    =          7.772 mm/us
The particle velocity =          1.832 mm/us
The speed of sound    =          5.941 mm/us
Gamma                 =          3.243

Cylinder runs:                 % of standards
  V/V0     Energy    TATB      PETN      HMX    CL-20   TRITON
 (rel.)   (kJ/cc)  1.83g/cc 1.76g/cc 1.89g/cc 2.04g/cc 1.70g/cc
   1.00    -0.89
   2.20    -4.84     100       76       65       53      111
   4.10    -5.80     100       75       66       55      105
   6.50    -6.21     100       75       66       56      102
  10.00    -6.49     100       75       66       57       99
  20.00    -6.83      99       75       67       57       95
  40.00    -7.08      99       75       68       58       92
  80.00    -7.28      99       75       68       59       88
 160.00    -7.45

Freezing occurred at T =     1800.0 K and relative V =   1.715
The mechanical energy of detonation =     -7.673 kJ/cc
The thermal energy of detonation    =     -0.000 kJ/cc
The total energy of detonation      =     -7.673 kJ/cc

JWL Fit results:
E0   =       -8.007 kJ/cc
A    =       851.62 GPa, B    =      7.60 GPa, C     =         1.22 GPa
R[1] =         4.86,     R[2] =      1.11,     omega =         0.36
RMS fitting error =   0.67 %
```

C.7.2 At measured 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     Mol.   TMD
                                 formation     wt.    (g/cc)
                                 (cal/mol)
dnan24      28.20  21.98  32.38   -44455   198.13     1.55 c7h6n2o5
nto         57.10  67.80  53.15   -24140   130.07     1.91 c2h2n4o3
rdx         14.70  10.22  14.47    16496   222.13     1.81 c3h6n6o6

Density  =  1.7500 g/cc   Mixture TMD =  1.7777 g/cc   % TMD = 98.4408

The C-J condition:
The pressure          =          24.28 GPa
The volume            =          0.437 cc/g
The density           =          2.289 g/cc
The energy            =           2.86 kJ/cc explosive
The temperature       =           3413 K
The shock velocity    =          7.674 mm/us
The particle velocity =          1.808 mm/us
The speed of sound    =          5.867 mm/us
Gamma                 =          3.245
```

```
Cylinder runs:             % of standards
  V/V0     Energy    TATB     PETN      HMX    CL-20   TRITON
 (rel.)   (kJ/cc)  1.83g/cc 1.76g/cc 1.89g/cc 2.04g/cc 1.70g/cc
   1.00    -0.85
   2.20    -4.70      97       74       63       52      108
   4.10    -5.65      97       73       64       53      102
   6.50    -6.06      97       73       64       54       99
  10.00    -6.33      97       73       65       55       97
  20.00    -6.67      97       73       65       56       93
  40.00    -6.92      97       73       66       57       90
  80.00    -7.12      97       73       66       58       86
 160.00    -7.28

Freezing occurred at T =     1800.0 K and relative V =   1.736
The mechanical energy of detonation =     -7.511 kJ/cc
The thermal energy of detonation    =     -0.000 kJ/cc
The total energy of detonation      =     -7.511 kJ/cc

JWL Fit results:
E0   =       -7.843 kJ/cc
A    =       821.63 GPa, B    =      7.38 GPa, C     =         1.22 GPa
R[1] =         4.87,     R[2] =      1.10,     omega =         0.36
RMS fitting error =   0.67 %
```