XP® : A cost effective approach for medium calibre Insensitive Munitions (IM)

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1 INTRODUCTION

This paper will describe the work led by Nexter Munitions in order to develop a 40 mm ammunition loaded with a low vulnerability explosive. Research works were undertaken for several years about low vulnerability explosive formulations and they conducted to the development of XF® melt-cast explosive family. In parallel, low vulnerability explosives manufactured by compression were also developed. Today, LU211 IM is part of Nexter Munitions products portfolio, being loaded with the well known XF® explosive. The medium calibre field of application represents also an important offer of Nexter Munitions' activities: for example, 30x150 mm SAPHEI ammunition for RAFALE and 30x113 SAPHEI ammunition for TIGER helicopter can be mentioned.

The aim of this document is to expose more accurately the development and the characterization of 40 mm ammunition loaded with a low vulnerability explosive. Works on this subject were initiated in 2006 and the first part of this paper will present a state of the art among the medium calibre ammunition and their associated explosive charge. To satisfy better safety requirements and to be in agreement with a growing customer demand, Nexter Munitions has tried to define the best ammunition / explosive charge choice to meet those requirements.

The first step was to find the best explosive satisfying an adequate level of safety. In addition, the second step was to select the explosive with interesting detonation characteristics in order to provide a correct level of terminal efficiency. The most commonly known explosives are issued from composite explosive formulations or manufactured by compression at hot temperature. Those technologies were not corresponding to the expected characteristics specified: the research of the best efficiency / cost ratio. Moreover, the choice made Nexter Munitions is a low vulnerability pressed explosive compliant with uniaxial pressing process at room temperature.

Following a brief state of the art, the major milestones of the explosive formulation development will be presented. The detonation performances, the mechanical and sensitivity properties, the productionization phase and some terminal efficiency characteristics associated with IM signature will be exposed.

2 STATE OF THE ART: MEDIUM CALIBRE AMMUNITION

2.1 Medium calibre ammunition market analysis

The customer spectrum of medium calibres corresponds to 20 mm up to 40 mm. The following table presents the different applications of the medium calibre ammunition with their corresponding weapon stations.

Ammunition range	Ammunition	Weapon station
Calibre 20 mm	20 x 102 mm 20 x 139 mm	Anti-aircraft gun, light armoured vehicle, aircraft and helicopters gun
Calibre 25 mm	25 x 137 mm	IFV gun, JSF-35 Fighter gun
Calibre 30 mm	30 x 113 mm 30 x 150 mm 30 x 173 mm	M2000 and RAFALE Fighters, TIGER helicopter, naval gun, IFV gun
Calibre 35 mm	35 x 228 mm	Anti-aircraft gun (Skyshield system), IFV gun
Calibre 40 mm	40 x 365 mm 40 mm CTAS	Anti-aircraft gun, IFV gun, naval gun

Table 1: Medium calibre and its applications

The Cased Telescoped Armament System (40 mm CTAS) is under development in CTA International (CTAI is a joint venture company 50/50 owned by BAE Systems and Nexter Systems). In CTAI portfolio, the General Purpose Round-AirBurst (GPR-AB) and General

Purpose Round-Point Detonating (GPR-PD) rounds are expected to be compliant with STANAG 4439 requirements. Consequently, CTAI made the choice to select a low vulnerability explosive composition. Nexter Munitions, which has the responsibility of the filled shell body, was asked to propose an explosive filling.

2.2 Explosive compositions available for medium calibre ammunitions

The first step for Nexter Munitions was to look for a low vulnerability explosive among existing compositions. Potential explosive candidates for medium calibre are splitted between melt-cast, cast-cured and pressed compositions [3], [4]. Two examples can be given:

- 40 and 57 mm ammunitions (Bofors) are currently filled with respectively Octonal (HMX/TNT/Al) and Hexotonal (RDX/TNT/Al) which are belonging to melt-cast composition family;
- 40 mm Bofors (IM version) is filled with a HMX/PU cast-cured composition.

Usually, for medium calibre ammunitions from 20 to 35 mm calibres, the pressed filling process is the preferred solution due to its low cost associated to a high production capability. After different benchmarkings with existing compositions such as PBXN-5 or other high performances pressed compositions, it has been concluded that:

- whether the composition does not answer the IM requirement (PBXN-5)
- or the filling process to use (hot or isostatic pressing) was not compliant with the cost objectives given by the customer.

As a consequence, Nexter Munitions made the choice to develop its own low vulnerability explosive pressed at room temperature.

3 EXPLOSIVE FORMULATION

3.1 Explosive composition properties

The different criteria selected by Nexter Munitions to develop this low vulnerability composition were:

- High detonation performances (at least as good as RDX/wax compositions used with medium calibre applications including detonating characteristics),
- Good mechanical behaviour within the operational temperature range [-46℃ ; 63℃]: to ensure both weapon / gun crew safety and a satisfactory level of terminal efficiency,
- Low vulnerability performances in order to be compliant with STANAG 4439 requirements.

So, the targeted performances can be summarized as following:

	Properties			
	Density ρ	VoD	Unconfined critical diameter	Gap Test LSGT
Targeted performances	> 1.8 $g.cm^{-3}$	> 7800 $m.s^{-1}$	< 10 mm	between 200 and 275 cards

Table 2: Targeted performances

The required mechanical characteristics are expected to be at least the same as the current RDX/Wax formulations filled in 25x137 mm ammunitions. The following table presents the mechanical properties for RDX/Wax composition, which is used for medium ammunitions:

RDX/wax composition	Density	Stress, max (MPa)	Young Modulus (MPa)	Deformation, max (%)
-40℃	1,82 $g.cm^{-3}$	10,6	1920	0,8
+20℃		8,7	2000	0,7
+65℃		1,7	400	0,6

Table 3: Mechanical properties of RDX/Wax composition [2]

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Considering these requirements, an experimental design was elaborated in order to build the formulation of the targeted and optimized explosive composition. To respect the cost / effective ratio required, Nexter Munitions has decided to develop a formulation based on a mixture of RDX and NTO. The main reasons of this choice were governed by the wish to get the best advantage of their low vulnerability behaviour (in particular regarding mechanical hazard); Nexter Munitions background using NTO based formulations has also played a major role.

3.2 Explosive formulation based on RDX and NTO

The Nexter Munitions R&T department developed several formulations dedicated to meet the requirement. These formulations were optimized by the methodology of experimental design which allows, through a rational experimental approach, to obtain the best compromise. In terms of comprise, we mean with respect to several parameters which influence the expected and targeted characteristics.

3.2.1 Explosive formulation optimization

The formulation of explosive composition is concerned with the mixing of various components in a way that they provide a final product with satisfactory properties such as low vulnerability, weak critical diameter and a process pressed under ambient temperature.
The research of optimal conditions required a compromise between NTO/RDX percentage (vulnerability properties), and aluminium percentage (blast effect generation and higher density). The optimal domain of experimentations, for the mix design, obtained by compiling this previous conditions is described in the Figure 1. The use of calculation tools allowed us to target the domain of interest concerning our formulation and to test the most relevant compositions. The detonation properties and theoretical densities were obtained with QUERCY calculation code. The vulnerability was assessed with the help of a calculation tool, called CS (Criterion of Sensitivity), developed by Nexter Munitions on the basis of the CHETAH software [8].

3.2.2 Formulation trials

To validate the experimental design, some calculations were performed with the calculation codes previously mentioned in order to optimize detonation velocity, theoretical density, CS criteria and Chapman-Jouguet detonation pressure for each selected formulation.
These calculations allowed to focus on 9 formulations in agreement with the expected performances. Therefore, the experimental domain could be chosen and it is represented by the following figure:

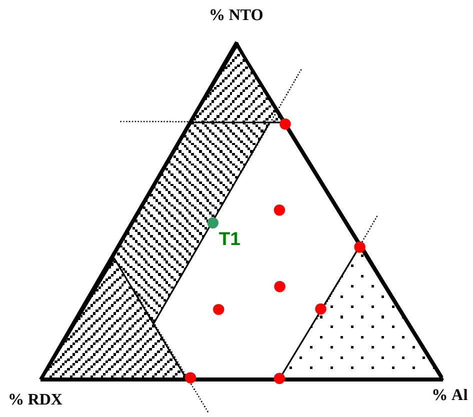

Figure 1: Experimental design

As it can be observed on Figure 1 (red dots), some trials were performed for formulations with no NTO or no RDX in order to describe the limits of the experimental domain. However, they do not present any interest in the perspective of a formulation to be selected.

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3.2.3 Detonics parameters evaluation

Detonation unconfined velocity and initiation tests were performed. Results are described in Table 3. Detonation velocity evaluation was performed with 25 mm diameter blocks for each of the 7 formulations selected (Formulations with no RDX and no NTO have not been performed).

Trial #	Initiation test	VoD measured ($m.s^{-1}$)
T1	Ok	7921
T3	NOk, no detonation transmission	7220
T4	NOk, no detonation transmission	7631
T6	Ok	7779
T7	Ok	7300
T8	Ok	7550
T9	Ok	6275

Table 4: Igniting test and detonation velocity

Among the 7 selected formulations, the different driving parameters were studied to determine the optimized and expected formulation (Figure 1, green dot), in particular regarding the density where a value over 1.8 $g.cm^{-3}$ was required. Explosive composition T1 allows us to find a compromise between the sensibility and the detonics properties. The global formulation of the composition T1 can be expressed as following:

	Properties			
RDX / NTO / Al / Wax 33% / 49% / 14% / 4%	Density ρ	VoD	Detonation pressure	Gap Test LSGT [1]
	1.82 $g.cm^{-3}$	7921 $m.s^{-1}$	285 kbar	230 cards

Table 5: Composition T1 properties

This composition is named **XP3264®**.

3.3 Sensitivity evaluation, mechanical and detonics properties

At the conclusion of the formulation step, the composition selected was called "XP3264®". The mechanical properties and pyrotechnic properties were performed. The results are given in the following tables.

	50% Go results	AFNOR standard
Friction sensitivity	0% at 353 N	NF T 70 503
Electrostatic Discharge	367 mJ	NF T 70 539
Impact Sensitivity	30 % at 50 J	NF T 70 500

Table 6: Pyrotechnic sensitivity XP3264®

Figure 2: Detonation Velocity and Critical Unconfined Diameter results

Detonation velocity was determined according to the NFT 70-700 AFNOR standard: the result was 7921 $m.s^{-1}$. The critical diameter was performed according to the NFT 70-701 AFNOR standard: the critical unconfined diameter was included between 5 and 10 mm.

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Mechanical properties had performed according to the NFT 70-314 AFNOR standard, the results are presented in the following table.

XP3264®	Density (g.cm^{-3})	Stress, max (MPa)	Young Modulus (MPa)	Deformation, max (%)
-45℃	1,82	12,9	710	2,1
+20℃		9,8	607	2,1
+70℃		2,8	204	1,6

Table 7: Mechanical properties – Explosive composition XP3264®

Mechanical properties were slightly better than those of RDX/Wax composition.

3.4 Industrial transfer: from laboratory to industrial workshop

The performances of the composition XP3264® are fully compliant with medium calibre ammunition requirements, and, especially with the 40 mm calibre. The following step of the programme was to transfer this laboratory process to an industrial process in Nexter Munitions - La Chapelle St Ursin facility. Today, the composition XP3264® is manufactured at the industrial workshop. The following figures show the industrial plant dedicated to XP3264®.

Figure 3: Coating apparatus in Nexter Munitions facility and view of XP3264® agglomerates

3.5 Other XP3264® applications

As previously described in the last paragraphs, XP3264® most commonly known application is dedicated to medium calibre cartridges filling. Nevertheless, it has recently been demonstrated it could be used as a booster for 155 mm artillery shells.
It was also demonstrated XP3264® could be used as main explosive for warheads application. At the beginning of 2000s, Nexter Munitions has successfully used XP3264® explosive filling for a fragmentation warhead for missiles application. The main results of this study [7] have shown a convincing terminal efficiency on a multiple target configuration; moreover, first IM experimentations led to a good behaviour of the charge (FCO: Type V reaction; BI: Type IV reaction).
These results constituted the first step of IM assessments with XP3264® composition and it allow to introduce now the additional experimental results performed with medium calibre applications (§5).

3.6 French MOD (DGA) homologation [1]

The XP3264® homologation according to STANAG 4170 is currently in progress under DGA/Techniques Terrestres responsibility and will be delivered (at industrial scale) at the end of 2010.

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4 XP3264 FILLING FOR 40CTA GENERAL PURPOSE ROUNDS

In 2006, Nexter Munitions launched a feasibility programme regarding a pressed filled 40CTA shell body. The first results obtained in the field of terminal efficiency and IM signature were very promising. CTAI, which is the design authority for 40CTA gun and ammunitions, decided to choose XP3264® as the filling explosive of both its GPR-PD and GPR-AB rounds.
Nexter Munitions designed and supplied a press compliant with 40CTA ammunition and a coating/granulating unit: this new press, associated with the XP coating/granulating unit was successfully qualified at the end of June 2010.
The gun firings performed during the qualification phase with GPR-PD rounds filled in La Chapelle facility have confirmed all the results obtained with "laboratory scale XP".

Figure 4: Press for 40CTA ammunition

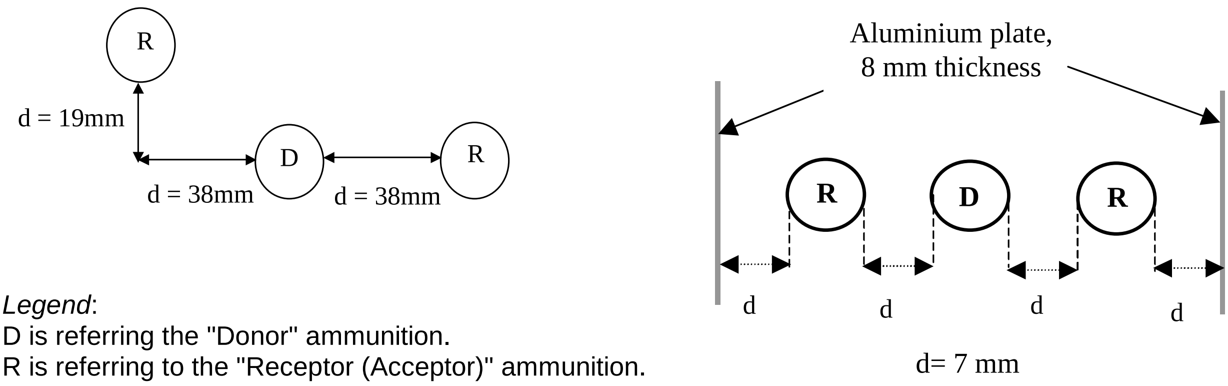
5 40 MM IM SIGNATURE

In order to status on IM signature level, a series of tests was performed on 40 mm ammunition loaded with XP3264® explosive. Among the tests needed to determine the whole signature, it is chosen to present in this paper the most significant results: sympathetic reaction, bullet impact, shaped charge jet impact and thermal tests. Each test performed is in agreement with the STANAG corresponding to the stimulus.

5.1 Sympathetic reaction (SR)

5.1.1 Description of tested configurations

To determine sympathetic reaction level, it was chosen to perform this test following 2 configurations. Indeed, with respect to the THA, two main configurations were of interest: on the one hand, the 40 mm ammunition without any packaging but in a geometric configuration compliant with the logistic one's was chosen (Figure 5 left), and on the other hand, the feed slot ammunition configuration was selected (Figure 5 right).



Legend:
D is referring the "Donor" ammunition.
R is referring to the "Receptor (Acceptor)" ammunition.

Figure 5: The two configurations (unpacked and feed slot) selected for SR tests

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The 40 mm cartridge embedded in propellant was used for each test. The main difference between the two configurations is lying in the separation distance, configuration at 7 mm being the most constraining one.

5.1.2 SR tests results

For each test, a witness plate was placed under the donor 40 mm ammunition initiated. It can be observed on Figure 6 is perforated, the donor playing fully its expected role.

Figure 6: left : SR result (unpacked configuration); right : SR result (feed slot ammunition).

For each SR test performed, the witness plate under the acceptor ammunition was not perforated leading to the conclusion that no detonation occurred. Moreover, propellant of the cartridge was dispersed but no reaction was also observed. The 40 mm shell body was found with no important damage.
The configuration test did not include any pressure measurement. Nevertheless, at the sight of the other results of the tests, it was concluded a Type V reaction level occurred for the two configurations.

5.2 Bullet Impact (BI)

5.2.1 Description of tested configuration

The test was performed within Nexter Munitions facilities. A weapon located into a tunnel was used to launch a 12.7 mm bullet (AP type M2) on the 40 mm ammunition cartridge. The expected velocity of 850 m.s^{-1} specified by the STANAG 4241 was reached after several tests adjustments without any cartridge to impact. The following figure is presenting the configuration test :

Figure 7: Weapon used for BI test and 40 mm ammunition before test

The aimed point for the impact of the bullet was chosen into the explosive part (XP3264®).

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5.2.2 BI test result

The main parts recovered after the test are presented hereunder:

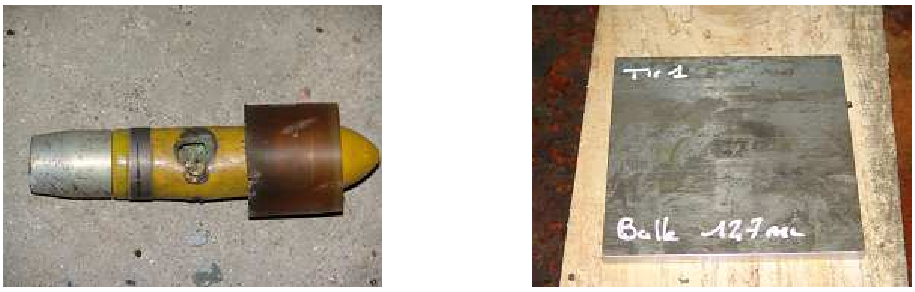

Figure 8: 40 mm Warhead after bullet impact test

It can be observed that the 12.7 mm bullet has fully perforated the ammunition (Figure 8 left), the witness plate was not damaged. XP3264® loading explosive and propellant have not reacted. It was concluded a Type V reaction has occurred.

5.3 Shaped Charge Jet Impact (SCJI)

SCJI test was performed adopting a configuration in order to be compliant with the STANAG 4526 characteristics. Instead of Rockeye to fire, the shaped charge used is the reference warhead produced par Nexter Munitions. Having a more important calibre than the charge referred by the STANAG, some softening plates were placed between the selected warhead and the 40 mm cartridge, being thus compliant with the researched jet characteristics.
The test was performed with the SC jet aiming at the loading explosive and the cartridge was located on a witness plate. The results and the main parts recovered after the test are presented on the following figure:

Figure 9: 40 mm after SCJI test

The 40 mm ammunition has not detonated: the shell has apparently fractured into those three main parts and B7T powder has not reacted. It was concluded to an explosion reaction level and a Type III was associated to this test.

5.4 Fragment Impact (FI)

Establishing an equivalent analysis with other products and regarding the level of reaction obtained with mechanical threats, a Type IV reaction level is estimated for the fragment impact (STANAG 4496).

5.5 Thermal threats

Some thermal experimentations were performed with 40 mm ammunition filled with PBX composition. The main results obtained are presented hereunder. A series of Slow Cook-Off (SCO) tests was performed with a 40 mm ammunition cartridge in agreement with the STANAG 4382. The 40 mm ammunition was introduced into a conditioning cell regulated in temperature in order to respect the expected 3.3°C/ h warming slope. A first test was performed with the ammunition located in a vertical position and a second test was performed with the ammunition horizontally. For these two tests, the opening of the cartridge was observed due to the pressure increase inside, the shell is recovered with no damages. It was concluded a

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Type IV reaction level has occurred. Some pictures of the test results can be presented as following:

Figure 10: 40 mm cartridge before and after SCO test

Regarding FCO, the test was performed in agreement the STANAG 4240. The configuration tested was involving a storage box of 40 mm filled XP® cartridges put into the fuel fire and no detonation occurred. It was concluded that a Type IV reaction level was observed.

Figure 11: 40 mm cartridge before and after FCO test

5.6 IM signature

The previous paragraphs present the tests performed for the major part of the stimuli that have to be assessed for the whole IM signature. Estimating the reaction level that could be reached for Fragment Impact and with the help of the previous tests results, the 40 mm ammunition signature is presented in the following table:

Stimulus	STANAG 4439	Signature 40 mm CTAI
FCO (Fast Cook Off)	V	IV (packed)
SCO (Slow Cook Off)	V	IV (packed)
BI (Bullet Impact)	V	V (packed)
SR (Sympathetic Reaction)	III	V (unpacked)
FI (Fragment Impact)	V	IV (estimated)
SCJI (Shaped Charge Jet Impact)	III	III (unpacked)

Table 8: IM signature comparison

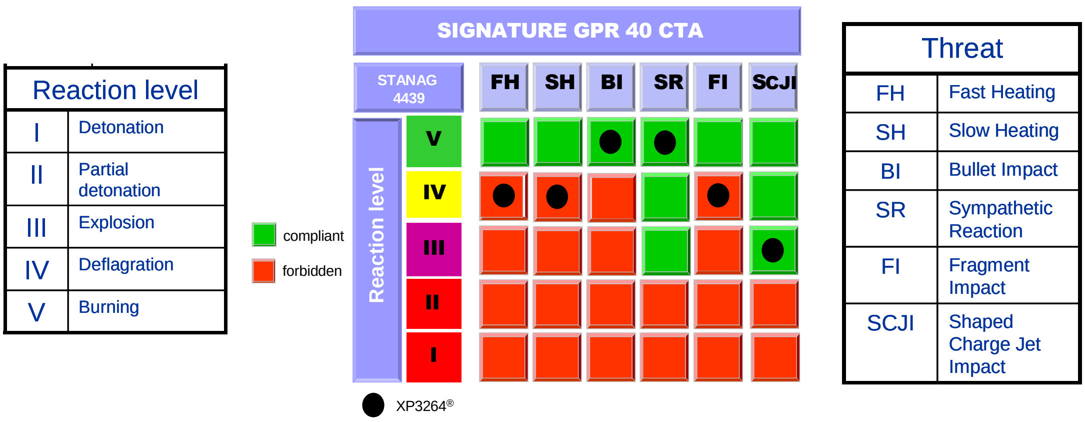

Figure 12: IM signature

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It can be observed that the 40 mm ammunition is not fully compliant with STANAG 4439 but it increases significantly the safety level of the ammunition if the comparison is made with traditional explosive composition for medium calibre. Those results are promising and the whole tests to determine the IM signature will be performed with the help of coming qualification programme.

6 TERMINAL PERFORMANCES CHARACTERISATION OF THE CARTRIDGE

Several fragmentation tests were performed for a static configuration. It allowed to determine accurately the fragment matrix of efficiency in order to estimate the terminal performances of the 40 mm ammunition.

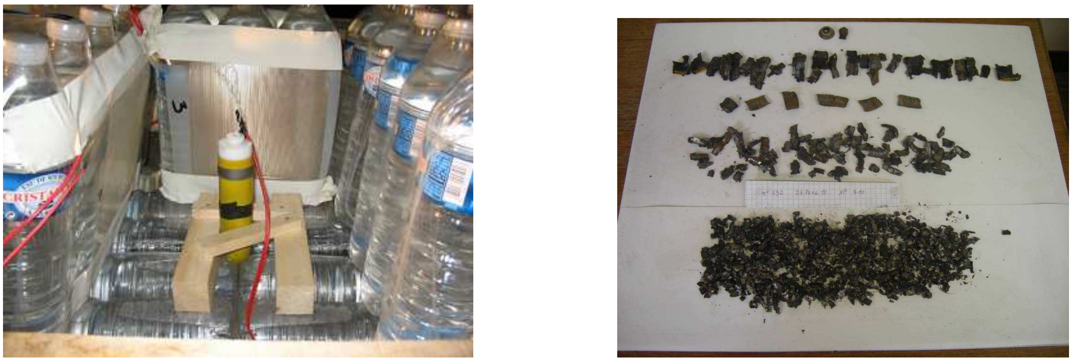

Figure 13: Fragmentation of 40 mm cartridge (static firing test)

A correct level of fragmentation was obtained for this kind of ammunition.

To complete this terminal performances characterization, some dynamic tests were performed with firings into a tunnel including some X-Rays measurements for some of them.

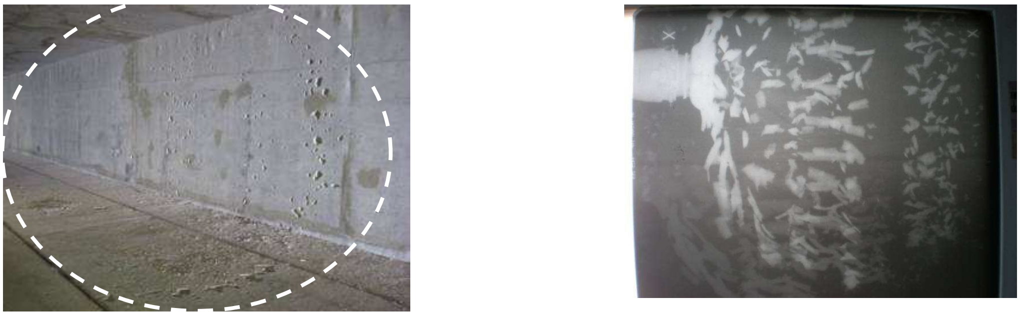

Figure 14: Cloud of fragments impacting the walls of the tunnel and X-Rays visualisation

Once more, those pictures are the witnesses of a good fragmentation level.

7 CONCLUSION

The explosive composition XP3264® was selected to be filled in 40 mm ammunition. This study began in 2006 under Nexter Munitions fundings. The explosive composition was characterized and assessed, its manufacturing process was qualified at a production stage in 2009.
Moreover this composition has been ratified by the French Authorities according to the STANAG 4170.
The detonics performances and the mechanical properties are fully compliant with the medium calibre requirements and the use of this composition allows to increase the global safety level of the 40CTA ammunition.

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