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Study on Interest and Cost of the Muratisation of Ammunitions of the French Army

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Introduction

This paper presents the methodology used in a technical and operational study about the « Interest and Cost of the Muratisation of Ammunitions of the French Army ». A systematic approach has been applied on four ammunitions : 120 mm OFL F1, 120 mm OECC, ERYX and 155 mm LU211. The tool used to complete this study is a software provided by the MSIAC : CBAM “Cost Benefit Analysis Model”. The most important part of the work is certainly the collect of several data for each case and their validation. One part of the data is linked to the lifecycle where numerous situations must be considered. For each situation, different events must be identified, probability of occurrences of these events must be determined and effects of this events must be estimated in term of financial cost. A support to estimate damages is the French decree 79-846 (1979).
Other requirements are the estimation of IM signature of considered ammunitions and knowledge of the IM state of the art in order to estimate signature, performance and cost associated to IM version of these ammunitions.
Data have been estimated by experts of the domain and a part of the validation has been made by the steering committee of the study.
The sensibility of the final result to the data has been studied in order to increase confidence in the results and to propose a simplified methodology.
The aim of this study is to contribute to build a future national strategy of acquisition of IM ammunition.

State of the art

The determination of the state of the art of IM technology is of primary importance in the determination of cost and performance of reference (non IM) and projected version (IM) of ammunition and as a consequence is an input data of the Cost Benefit Analysis. A state of the art of IM technology has been completed [1] with support of Club MURAT (association of French industrial companies) and MSIAC [2,3,4]. For a large number of applications, technological tools are available (from energetic materials to design technologies).

Attention has been paid to formulation of hypothesis associated with this state of the art concerning reduction of vulnerability of the system, cost and performance.
For each ammunition, a document (see annex, example of OECC ammunition) has been built with different information [5] :

- a general description of the ammunition and its components (case and energetic material) ;
- an estimation of IM signature of the ammunition ;
- hypothesis of IM amelioration carried out by analysis of the state the art ;
- an estimation of the IM signature of the projected version ;
- an estimation of performance and cost associated to the fabrication of the projected version.

Documents have been built for the following ammunitions : 39 calibre (OE 155 F2, OGRE 155, BONUS 155), 52 calibre (LU 211, LU 211 M, OGRE, BONUS, M2PA), OFL 120 F1, OECC 120 F1, POLYNEGE, GPR 40 mm, 25 mm OEIT, ERYX, HOT, MILAN, MISTRAL, MLRS, AT4CS, 81 mm and 120 mm mortar, mine dispersible F1, mine HPD F2, F3 and F4.

Lifecycle

This cost benefit analysis is run by the detailed description of the lifecycle of the ammunition from the production to the demolition. For each phase of the lifecycle, risks seen by the ammunition (accident or attack with a probability of occurrence associated to this risk) and financial consequences caused by the reaction of the ammunition are described (probability of reaction of the ammunition, material and people damaged or killed if reaction occurs, cost of destroyed material …). Consequences are studied for the reference and the projected version of ammunition.
In order to have all information required by the simulation, some hypothesis have been formulated concerning the probability of aggression or accident during each phase of the lifecycle [6].

The different phases of the lifecycle are listed below :
- development phase ;
- production phase ;
- transport from the plant to the principal storage area ;
- principal storage area phase ;
- change of storage area phase ;
- training phase in France *;*
- training phase during overseas period ;
- engagement phase ;
- destruction phase.

During those phases, the ammunition can see situations where aggression or accident probabilities are different. Those situations are listed below :
- handling of ammunition conditioned on transport pallet or container ;
- logistic transport of ammunition by train, ship or vehicle ;
- storage of ammunition in building, on vehicle or in a harbour ;
- intervention on the material ;
- use of ammunition ;
- tactical transport of ammunition to the firing field.

Assessing the consequences related to an aggression against munitions

In order to estimate the extent of the disaster resulting from an aggression on munitions, various scenarios had to be defined at each step of the lifecycle in terms of :

- scenario : arrangement of munitions and military means on the field as well as the position of the crew ;
- danger zones associated to the reaction of munitions for the different types of aggressions which are relevant for the considered at this step ;
- induced damages such as destruction of military means, injuries or even death of crew.

Identification of the relevant aggressions

For each step of the life cycle, the relevant aggressions which have to be considered were identified among the following list :

- rapid heating ;
- slow heating ;
- bullet impact ;
- fragment impact ;
- shaped charge jet impact ;
- sympathetic reaction.

Sympathetic reaction was considered as an aggression related to the terrorist threat for several storage conditions : munitions onboard wheeled vehicles or stored on quay or during external operations.

Risk divisions of the munitions

For each type of munitions, the risk division has been established on the basis of the rules which are stipulated by the French Decree 79-846 [7].

For the ammunitions which do not meet the MURAT requirements, the quantity of reactive explosive is assumed to be the total of explosive contained in all the munitions even if only one of them has been aggressed.

Referring to the French decree 79-846, the risk divisions are :

- kinetic effect ammunitions : Risk division 1.2
- Shaped charges ammunitions : Risk division 1.1
- Artillery ammunitions : Risk division 1.1

In case of « MURAT » ammunitions, the risk division is 1.2 « Risque unitaire » was considered. This allows limiting the explosive quantity which has to be taken into account for calculating the danger zones to the explosive contained in the single aggressed ammunition.

Danger zones

In accordance with the French decree 79-846, the danger zones are defined through various designations Z1, Z2,…associated to specific levels of damage.

Zone designation	Z_1	Z_2	Z_3	Z_4	Z_5
Foreseeable Injuries	Mortality > 50 %	Severe injuries (potentialy mortal)	Injuries	Potential injuries	Slight injury (low probability)
Foreseeable Equipment Damages	Severe damages	Important damages	Moderate damages	Slight damages	Very slight damages

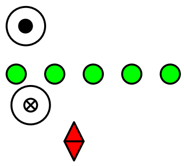
The calculation of the danger zones associated to the reaction of munitions – for instance in case of risk division 1.1 – is based on the following table :

Zone designation	Z_1	Z_2	Z_3	Z_4	Z_5
Radius of the zone around the quantity Q of reacting explosive	$0 < R_1 \leq 5\ Q^{1/3}$	$< R_2 \leq 8\ Q^{1/3}$	$< R_3 \leq 15\ Q^{1/3}$	$< R_4 \leq 22\ Q^{1/3}$	$< R_5 \leq 44\ Q^{1/3}$

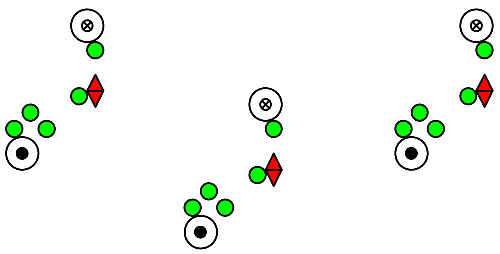
Description of the scenario

For a better understanding of the subject, the case of an artillery battery will be taken hereafter as an example. The considered step will be the firing of an artillery battery on the field, that is to say :

the artillery gun
the artillery crew
the trailer
the carried munitions



During the firing phase, the crew takes the munitions off the trailer and puts them in a line on the ground being equipped with the fuse. Munitions are then loaded in the gun and fired. However the artillery guns are arranged within batteries and are therefore in the vicinity of other guns, munitions, trailers and associated crews.



Assessing the consequences of an aggression

This analysis will be of course dependant on the vulnerability of the munitions.

1/ Munitions which do not meet the « MURAT » requirements

If an aggression occurs on munitions which do not meet the MURAT requirements, the quantity of explosive Q will be obtained by summing the quantities of explosive contained in all the munitions. In this example, Q = 393,6 kg.

The danger zones are therefore calculated as following :

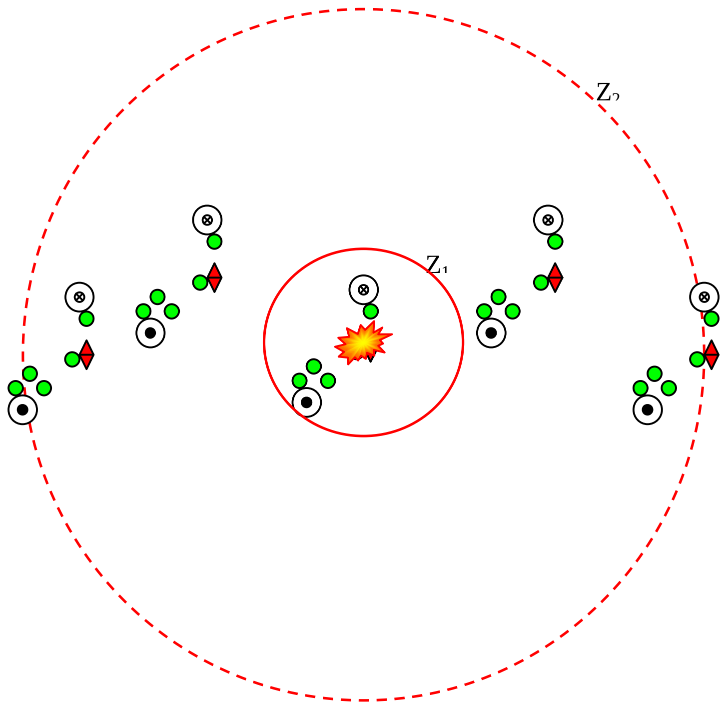
Zone designation	Z_1	Z_2	Z_3	Z_4	Z_5
Radius of the zone around the quantity Q of reacting explosive	$0 < R_1 \leq 5\ Q^{1/3}$	$< R_2 \leq 8\ Q^{1/3}$	$< R_3 \leq 15\ Q^{1/3}$	$< R_4 \leq 22\ Q^{1/3}$	$< R_5 \leq 44\ Q^{1/3}$
Q = 393,6 kg	37 m	59 m	110 m	162 m	323 m

A second calculation of the danger zones is then run for RD 1.2 objects :

Zone designation	Z_1	Z_2	Z_3	Z_4	Z_5
Radius of the zone around the quantity Q of reacting explosive	$0 < R_1 \leq 25$	$< R_2 \leq 135$	$< R_3 \leq 300$	$< R_4 \leq 400$	$< R_5 \leq 800$
Q = 393,6 kg	25 m	135 m	300 m	400 m	800 m

The final danger zones have been obtained by considering the maximum values of the two former calculations :

Z_1	Z_2	Z_3	Z_4	Z_5
37 m	135 m	300 m	400 m	800 m



Assessing the consequences of the aggression consists in an analysis of the position of the equipment and crew personals in the various danger zones.

Therefore, the consequences will be :

destruction of the 5 artillery guns ;
destruction of the 5 trailers ;
death of the crew members in the Z1 zones ;
injuries for the crew members of the four other guns ;
destruction of the munitions associated to the central gun

Furthermore, it has to be verified that there will be no transmission of reaction to the munitions of the two other guns.

The maximum ranges which could lead to a reaction are calculated in the two cases :

- transmission through blast effect :

$R = 0,5\ Q^{1/3}$

In this example : R = 4 m

- transmission due to fragments :

$R = 2,4\ Q^{1/3}$

For our example : R = 18 m

It appears there is no transmission to the munitions associated to the other guns.

2/ Low vulnerability Munitions « MURAT »

In that case, the danger zones which had been calculated for the DR 1.1 will be reduced in comparison to the former example as the quantity of explosives will be limited to the one contained in a single ammunition.

Zone designation	Z_1	Z_2	Z_3	Z_4	Z_5
Radius of the zone around the quantity Q of reacting explosive	$0 < R_1 \leq 5\ Q^{1/3}$	$< R_2 \leq 8\ Q^{1/3}$	$< R_3 \leq 15\ Q^{1/3}$	$< R_4 \leq 22\ Q^{1/3}$	$< R_5 \leq 44\ Q^{1/3}$
Q = 11,4 kg	12 m	18 m	34 m	50 m	100 m

In the same manner, the danger zones which had been calculated for the DR 1.2 will be reduced in comparison to the former example as the quantity of explosives will be limited to the one contained in a single ammunition.

Zone designation	Z_1	Z_2	Z_3	Z_4	Z_5
Radius of the zone around the quantity Q of reacting explosive	$0 < R_1 \leq 25$	$< R_2 \leq 135$	$< R_3 \leq 300$	$< R_4 \leq 400$	$< R_5 \leq 800$
Q = 11,4 kg	17 m	90 m	200 m	267 m	534 m

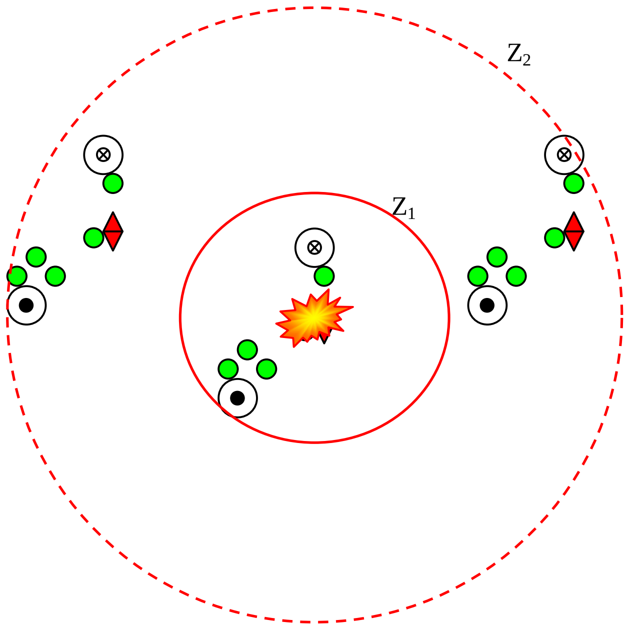
The danger zones associated to the RD 1.3 objects are calculated by considering the whole mass of active material :

Zone designation	Z_1	Z_2	Z_3	Z_4
Radius of the zone around the quantity Q of reacting explosive	$0 < R_1 \leq 1{,}5\ Q^{1/3}$	$< R_2 \leq 2\ Q^{1/3}$	$< R_3 \leq 2{,}5\ Q^{1/3}$	$< R_4 \leq 3{,}25\ Q^{1/3}$
Q = 393,6 kg	11 m	15 m	19 m	24 m

The final danger zones will correspond to the maximum range among all of them :

Z_1	Z_2	Z_3	Z_4	Z_5
17 m	90 m	200 m	267 m	534 m

Assessing the consequences of the aggression consists in an analysis of the position of the equipment and crew personals in the various danger zones.



In this example, the consequences will be :

- destruction of 3 artillery guns,
- destruction of 3 trailers,
- death of the crew members inside the Z1 zone,
- injuries for the crew members associated to the 2 other artillery guns,
- destruction of munitions of the battery guns beeing aggressed.

This example illustrates the significant reduction of the consequences after an aggression on « MURAT » munitions.

Simulation

The simulation have been completed with the help of CBAM software (Cost and benefit Analysis Model) of the MSIAC [8].
Once the lifecycle has been implemented in CBAM and all frames filled up with the important number of data resulting from our collect of information and our preliminary calculations, the principle is to complete calculations for both reference (no IM) and projected ammunition (IM) and to compare them.

It rapidly appears that production and engagement phases run the result of the cost / benefit simulation. This result is illustrated by figure 1 and has been verified for 120 OFL, 120 OECC, 155 LU 211 and ERYX anti tank missile.

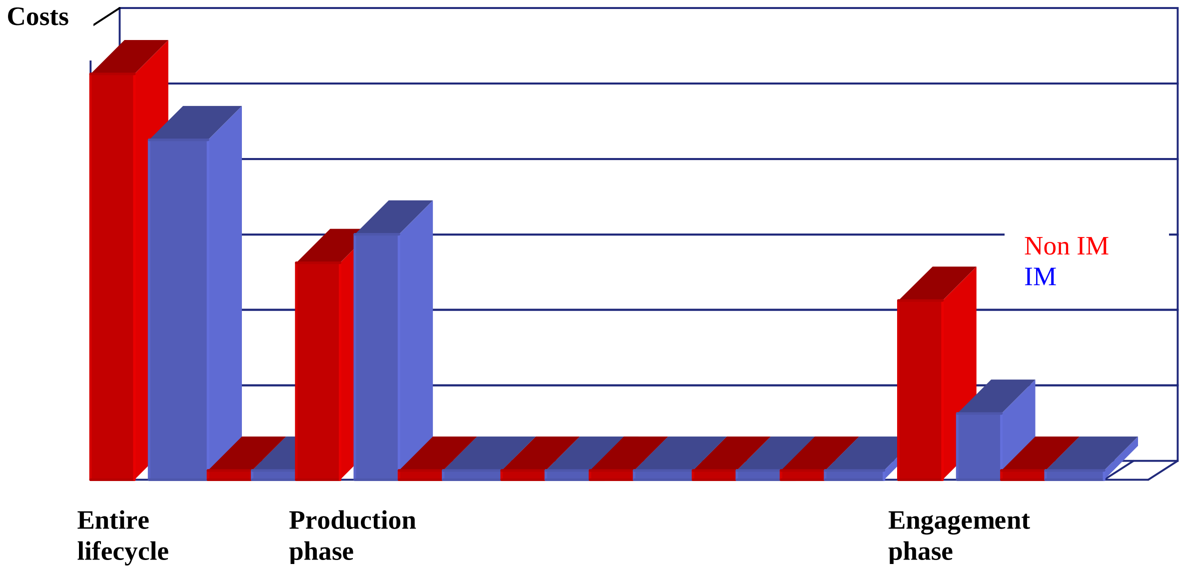


***Figure 1** : cost benefit general tendencies*

This result carried out, we decided to study in detail those two phases and the impact of input data on the simulation result.

Zoom on production phase :

The cost generated by the production phase is directly run by the cost of the munitions. So to appreciate the impact of this input on the simulation result, we completed different simulation with overcost of IM ammunition from 5 to 100% for the propulsive system and for the explosive charge. This kind of simulation is necessary since price of munitions depends on production volume. Results on the OECC ammunition are presented in figure 2a and 2b.

non-IM	2 350 €
50 % on explosive	2 644 €
50% on explosive + 5% on powder1	2 658 €
50% on explosive + 15% on powder1	2 687 €
50% on explosive + 50% on powder1	2 789 €
100 % on explosive	2 938 €
100% on explosive + 5% on powder1	2 952 €
50% on explosive + 5% on powder2	2 963 €
100% on explosive + 15% on powder1	2 981 €
50% on explosive + 15% on powder2	3 021 €
100% on explosive + 50% on powder	3 083 €
50% on explosive + 50% on powder2	3 224 €
100% on explosive + 5% on powder2	3 257 €
100% on explosive+ 15% on powder2	3 315 €
100% on explosive + 50% on powder2	3 518 €

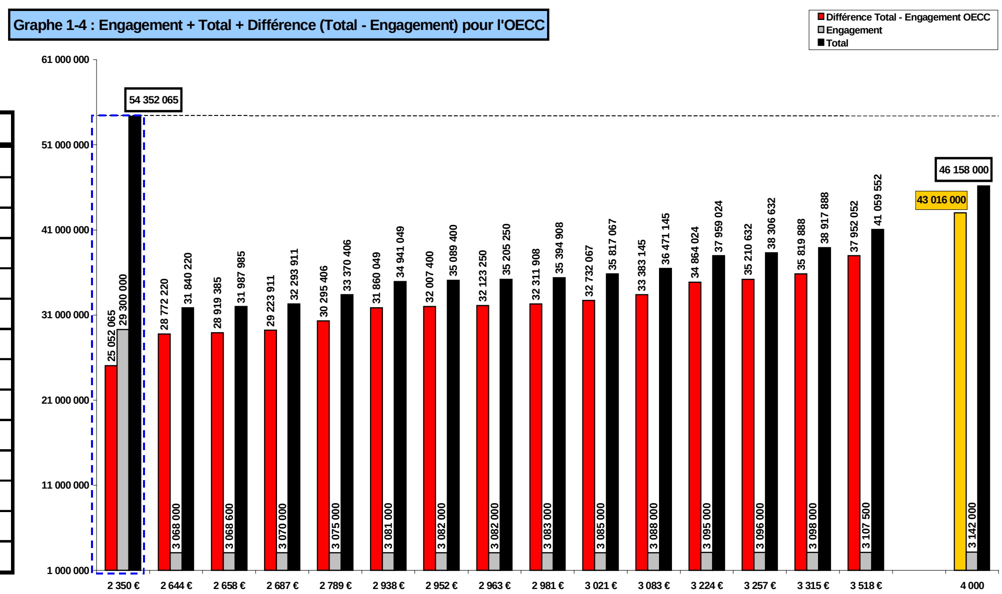


***Figure 2** :*
a) different hypothesis of cost of the IM version of OECC
b) impact on cost for the engagement phase and on the entire lifecycle

We have to notice that whatever the cost of the ammunition is, the engagement cost will not be influenced by the price of the ammunition, this observation has been verified on other ammunition even those that are more expensive like anti tank missile (ERYX) because the cost of this phase is essentially supported by the cost of destructed materials around the ammunition.

Zoom on engagement phase :

Cost generated by this phase is directly influenced by the risk probability affected to each aggression or accident in each situation. We completed a parametric study in order to appreciate the effect of those probabilities on the simulation result for different situations. Figure 3 presents the result for the entire engagement phase of ammunition ERYX (all situations) for probabilities of occurrence of aggressions multiplied by 1 to 1000.

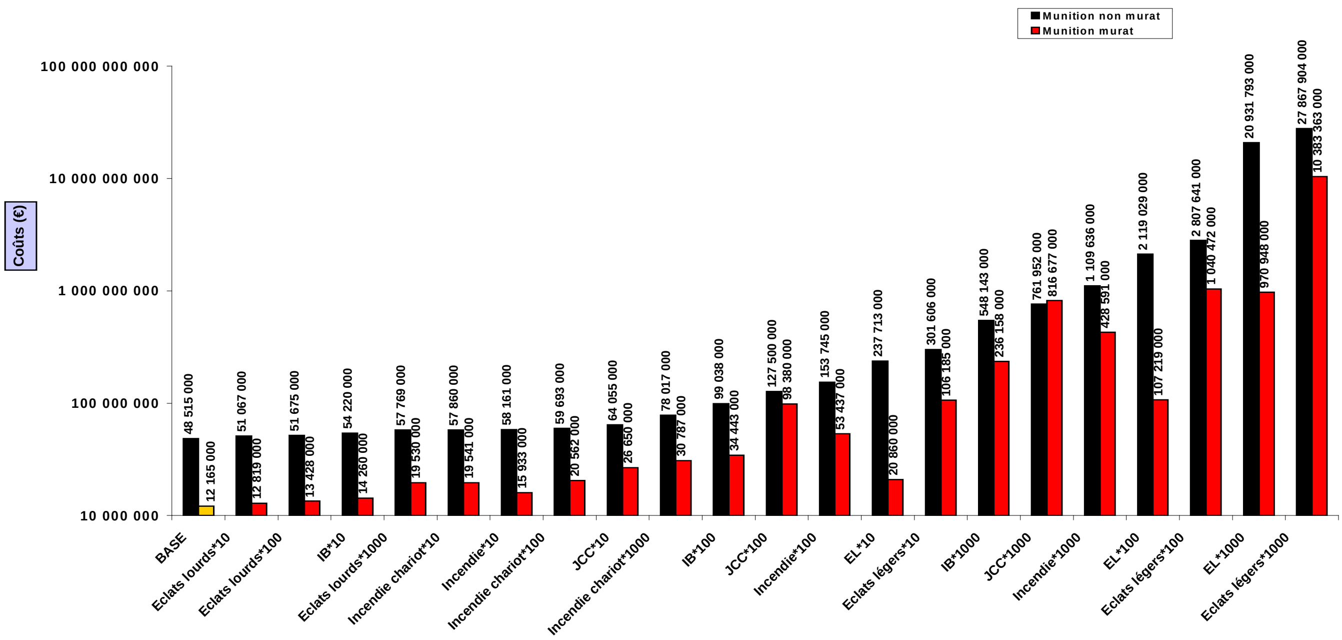


***Figure 3** : impact of the risk probability on cost of the engagement phase for the ERYX anti tank missile*

The strong dependence of simulation results with value of the probability of occurrence shows it is necessary to consolidate this input. On the example, a multiplication by a factor 10 of this probability for the shaped jet charge aggression has the consequence to multiply the cost of the engagement phase by seven. The particular attention paid on the shaped jet charge aggression is legitimate if we consider that this aggression proliferates today.

Figure 4 provides the relative influence of each situation on the entire cost of the engagement phase for the ERYX missile. The two main sources of cost are the tactical transport and the storage.

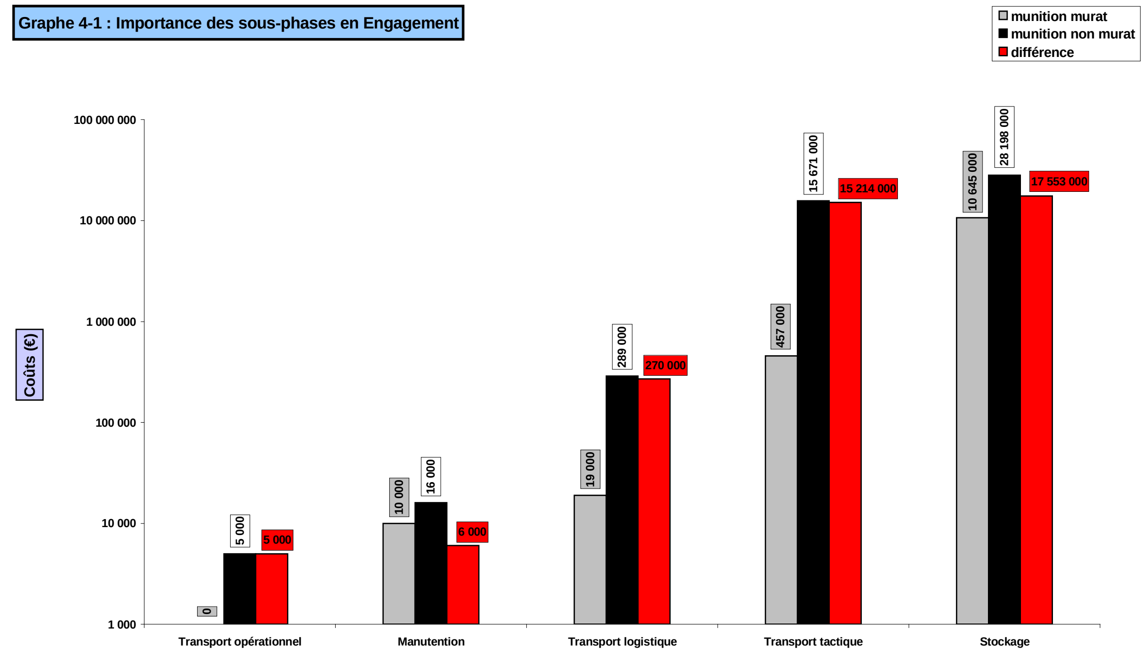


Figure 4 *: influence of each situation on engagement cost for the ERYX anti tank missile*

Figure 5 presents the relative part of each risk on the engagement cost for the ERYX missile.

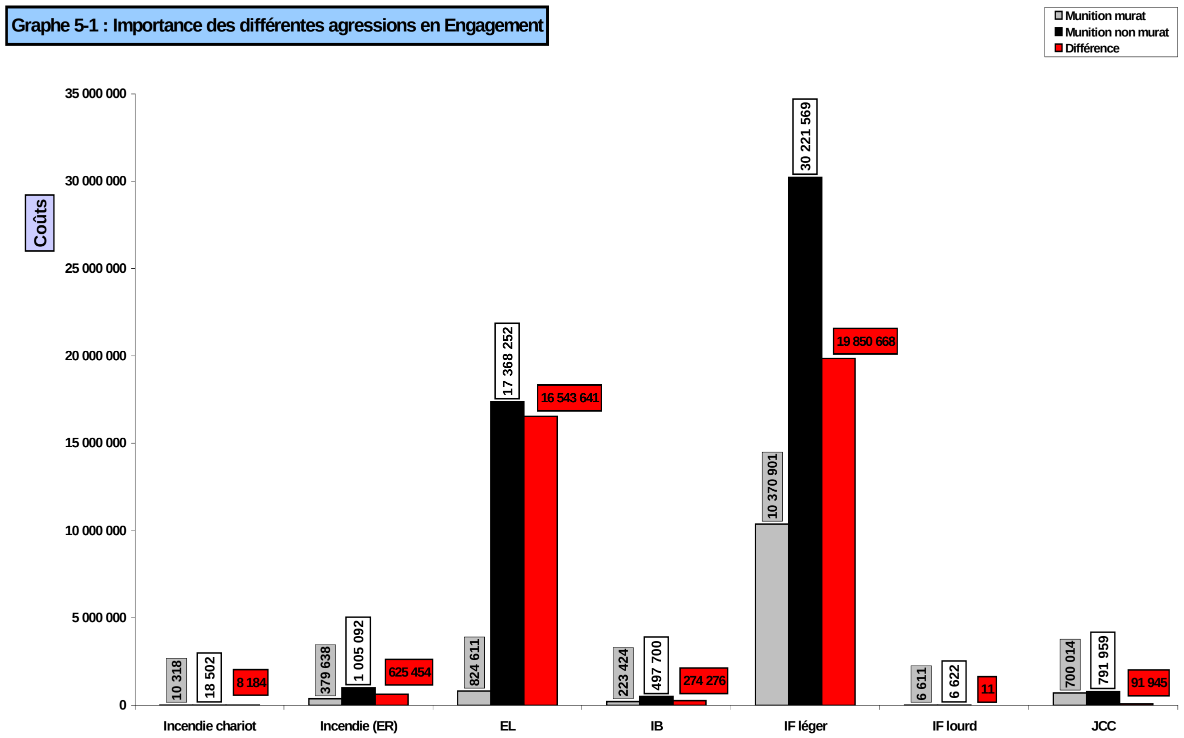


Figure 5 *: relative part of the different aggressions or accident on the engagement cost for the ERYX missile*

For the reference version of ERYX (non IM), the light fragment and slow heating aggression are responsible of a large part of the total cost of the engagement phase.
For the projected version (IM), it is only the slow heating which is responsible of the overall cost of the engagement phase. Those results can be explained and are direct

consequences of IM signature estimation of the ERYX and hypothesis of amelioration of this signature formulated for each ammunition at the beginning of the study.

Several interesting results can be extracted from the CBAM simulation. Nevertheless, the data collection in CBAM is quite dull. The different parametric results presented at the end of the paper show the necessity to consolidate some data (risk probabilities, operational scenario, hypothesis on cost of IM version depending on production volume) which have an important influence on simulation results.

Conclusions

A complete cost-benefice analysis was conducted on four French Ammunitions. Based on the CBAM tool developed by MSIAC, this work has allowed to identify strong tendencies concerning cost reductions associated to the use of « MURAT » ammunitions.

This analysis has also emphasised the great amount of data which have to be available to run such calculations, especially related to the engagement phase. If many of them – especially for the operational aspects – have to be assumed through data bases which have still to be consolidated, it appears that significant conclusions may be drawn.

From this detailed approach, a parametric study is suggesting that a simplified analysis could be profitable for being applied to a larger panel of ammunitions from mines to anti tanks missiles and from small to large calibre ammunitions

Finally, it has to be pointed out that this work is part of a more general effort taking into account the cost-benefice analysis but also media or political considerations to propose orientations for a future doctrine for « Muratisation » of the French Army ammunitions.

References :

[1] : B.Longuet, A. Yodo, JP. Brauge, Internal report ETBS n° 2351 « Etat de l'art des technologies MURAT » (2005)
[2] : Technical report of Club MURAT n°04/053/CM/ET O/S/DB/N du 09/06/04 « Bilan sur les acquis en matière de muratisation »
[3] : Technical report of Club MURAT n°04/076/CM/ET O/S/DB/L du 20/10/04 « Signature MURAT de différentes familles de munitions »
[4] : L101 document, 02/04 « report on the state of the art of IM design technology », Powell, Marchandin, Peugeot, MSIAC, (2003)
[5] : B. Longuet, A Yodo, Internal report ETBS n°26 26 "Compilation fiche munitions : version de référence/version projetée" (2005)
[6] : CBAM Threat and Probability Database
[7] French decree n°79-846 du 28/09/79 « Règles générales d'hygiène et de sécurité dans les établissements pyrotechniques »
[8] : L-104 guide, 01/04/04 « THE NIMIC COST AND BENEFIT ANALYSIS MODEL : USER GUIDE AND INPUT DATA COMPILATION »
[9] : N. Riehl, rapport de fin d'études ENSIETA « Etude Coût / Bénéfice de la muratisation des munitions du combat terrestre », (2005)
[10] : F. Barioz, technical report ETBS « Etude paramétrique sur les données d'entrée de CBAM » (2005)

Annex

<u>Short presentation of the 120 mm OECC ammunition.</u>

The ammunition is constituted of :
- a combustible cartridge based of nitrocellulose
- B 19T (1,6) gun powder
- an igniter with black powder
- a warhead charged with a RDX/TNT based explosive

<u>Presentation of the logistic and tactic case</u>

The logistic case is a GIAT 21 model. The individual case is composed of a part in high density polyethylene (PEHD-THP M) and a part in rigid moss.

The wrapped ammunition are then stocked on wooden pallet.

<u>Estimation of the IM signature</u>

	ER	*EL*	*IB*	*RI*	*FL* léger	*FL* lourd	*CC*
NR							
V							
IV							
III							
II							
I	X	X	X	X	X	X	

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The warhead signature runs the total signature.

IM technology available

Changing the explosive is necessary to improve the IM signature of the ammunition. A solution could consist on changing the RDX/TNT based explosive composition (hexolite 62/38) by a composition less sensitive type V350-B3014. The performance could be of the same range. An effort on the propulsive system could also improve the signature but there is not really something available looking the state of the art.

Description of the IM version
Replacement of hexolite 62/38 by V 350- B 3014

IM signature of the IM version

	ER	*EL*	*IB*	*RI*	*FL* léger	*FL* lourd	*CC*
NR							
V	X		X				
IV					X		
III		X					
II							
I				X		X	

The remaining problem (the sympathetic reaction level) is due to the vulnerability of the propulsive system. B-powder adapted to this calibre are known to fail the sympathetic reaction test. In logistic case, the reaction level of the sympathetic reaction aggression can be improved depending on its properties. In tactical configuration, a work on the configuration of the pallet storage could also allow to pass this aggression.
The amelioration of the intrinsic sensibility of the gun powder should be very expensive because there aren't any gun powders available for this calibre which pass through the sympathetic reaction test. Gun powder like YH family have good IM properties but present problem of ignitiability and erosivity.

Outlook on performance and cost
Performance of this ammunition can be conserved because there are lots of explosive composition available on shelves. Cost of this modification depend really of the scale of production. TATB explosive are nevertheless intrinsically more expensive than other granular explosive. If the objective is an ammunition fully IM compliant, the cost will not be the same regard to the lack of ideal gun powder on shelves. YH gun powder are still expensive because of their process of fabrication (re crystallisation of RDX) and have still problems of ignitiability. Progress in ignition system (ITLX or ETC) could be solutions to ignite those gun powders.