

Considerations of explosive trains in artillery rounds during service life and use



Figure 1

ABSTRACT

This report covers the key design elements of an artillery shell going into detail on the various components that encompass an artillery shell such as the fuze, payload and rotating band to name a few. Also discussing the problems that can occur in certain storage, transportation conditions and how alternative explosive fills with insensitive munition fills aid this. This topic is important as the war in Ukraine continues, countries that have gifted artillery rounds have been looking for replacements. Rounds that encompass the insensitive munition requirement will continue to develop and manufacturing costs will fall.

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INTRODUCTION

This report covers the key design elements of an artillery shell going into detail on the various components that encompass an artillery shell such as the fuze, payload and rotating band to name a few. Also discussing the problems that can occur in certain storage, transportation conditions and how alternative explosive fills with insensitive munition fills aid this.

Artillery shells are fired from a variety of platforms. The Asgo utilises a tracked platform, Archer utilises a wheeled platform and a number of towed wheeled artillery pieces. The end result will decide what system you use and what munition it is paired with.

DESIGN FEATURES

FUZE

The fuzing system on an artillery shell consists of a sensitive explosive such as tetryl, PETN and PBXN. Each fuze has a specific net explosive quantity in the region of 20g. The fuze contains at least two safety features that will not be initiated other than when used for its intended use. Set back and centrifugal forces are often used to arm the fuze. This ensures that the fuze is unable to function during storage and transportation. Artillery shell design will depict the type of fuze fitted to the munition. Examples include; percussion, time, graze, air burst, base and multi-function. Reinforcement is also required if penetrating a bunker for example to ensure the event happens inside the bunker rather than on impact with the roof. High tech fuzes can also be programmed before or during the loading cycle. This could include target data, initializing information for satellite navigation and data communication. [1]



Figure 2- Chinese MD-81 proximity fuze [31]

BOOSTER

The booster is used to detonate the main charge. This is located at the base of the fuze, allowing for the transfer of energy from a small amount of sensitive explosive igniting the main charge when the fuze functions. One example of an explosive booster used in the detonation chain is ROWANEX 3601 booster pellet. This consists of 35% RDX, 60% TATB and 5% Viton binder. PETN is also commonly used. "The explosive's sensitivity, high brisance, and small reaction zone allow it to detonate well over a large range of initial densities." [2]

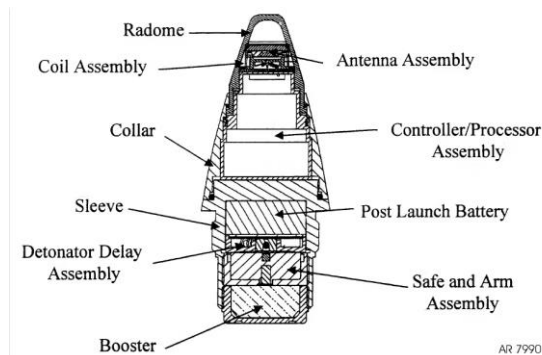


Figure 3- M782 fuze [3]

PAYLOAD

TNT, which is a secondary explosive is the standard fill for high explosive artillery shells. This is mainly because of the relative ease and cost to manufacture. TNT has the ability to be melted and cast into the desired munition whether this be the OF-462 artillery shell with 3.6kg NEQ or TM-62M anti-tank mine with 7.5kg NEQ to name a few.

One undesirable attribute of TNT is that when the shell is cast, cracks can form if not manufactured correctly with all impurities removed. If these impurities were to remain exudation would occur from the TNT. This can cause an increase in impact and friction sensitiveness. "TNT exudate is formed due to the presence of DNT, and other impurities within TNT, combined with the high temperatures that can be experienced in the service environment of munitions filled with TNT containing explosive compositions." [4]

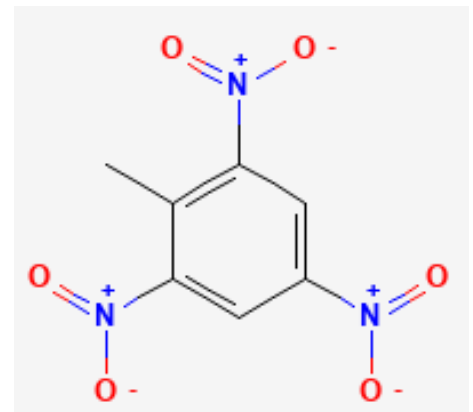


Figure 4- TNT 2D chemical structure [26]

The manufacturer must pay attention to the solidification process.

"TNT contracts by 11-12% on cooling and results in cracking and de bonding. In order to prevent cracking and de-bonding, controlled cooling processes as in the case of the 'Meissner Process' are employed" [5] This can also happen if stored in hot climates such as Afghanistan. The constant heating and cooling from day to night can exacerbate this with temperature differences of 15°C [6] recorded in a single day, this is called diurnal cycling.

As well as the practical aspect of casting TNT other factors must be considered such as the impact on the environment both when manufactured, once used for the munitions desired effect and on the human body. TNT is classed as a possible human carcinogen. [7] Impact areas where TNT

munitions have been used and areas around manufacturing plants have been known to have TNT contamination in soil samples. “The majority of TNT may be degraded in the surface soil at impact areas; however, small quantities can reach shallow groundwater (CRREL 2006).” [7]

2,2',4,4',6,6'-hexanitrostilbene (HNS) is added to TNT to get more TNT mass in the same volume (increase in density) due to smaller crystals and increase melting point up to 120 degrees. 0.3-1% HNS incorporated into the mixture is enough to record measurable improvements in performance. [8]

A liner is commonly used to reduce friction between the explosive fill and the body of the artillery shell during flight as the munition rotates due to the rifling of the barrel. This is a trade off with stability during flight. “Cast cure explosive projectile fillings are typically intended to not adhere or only partially adhere to the projectile interior. This intentional non-adherence is intended to avoid inconsistent body adhesion and explosive tearing or cracking due to the relatively high thermal expansions of cast cure explosives.” [9] Shear deformation and Adiabatic heating can occur on launch due to the setback forces experienced by the munition. These forces can cause localised heat in the main fill causing a premature detonation. This could occur before the shell has left the barrel causing a breach explosion. [10]

TNT is just one form of payload. Other examples include smoke, chemical, illumination and leaflet propaganda.



Figure 6- Russian propaganda shell [11]



Figure 5- Types of artillery shell [30]

ALTERNATIVE TNT FILL

“TNT was first used as an explosive in 1904 (although it had been used previously in the dye industry)” [12] Major manufacturing started in 1916 due to the start of World War 1. However due to the limitations of TNT discussed above alternatives have been trialed and tested. IMX-101, IMX-104 and MCX-6100 are all classed as insensitive munitions and have been tested for replacing TNT.

IMX-101

IMX-101 has been chosen as the replacement to TNT fill due to the change in insensitive munition (IM) requirements, whilst still matching or exceeding performance requirements. IMX-101 consists of 2,4-Dinitroanisole (DNAN) (43.5%), Nitroguanidine (NQ) (36.8%) and 3-Nitro-1,2,4-triazol-5-one (NTO) (19.7%).

The US has completed comprehensive IM testing on both TNT and IMX-101. TNT fails all insensitive munition tests whilst IMX-101 passes all but one. [13]

IM Test:	Fast Heating	Slow Heating	Bullet Impact	Fragment Impact	Sympathetic Detonation	Shaped Charge Jet Impact
Passing Criteria	Type V	Type V	Type V	Type V	Type III	Type III
M795 Baseline (TNT)	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL
M795 with IMX-101	PASS	PASS	FAIL*	PASS**	PASS	PASS

Figure 7- IM Test [13]

IMX-104

IMX-104 has been chosen as the replacement for TNT in mortar shells, again, due to the IM properties. These are similar to IMX- 101 and replace the Comp B composition. IMX-104 is also undergoing testing for use in the 155mm artillery shell. IMX-104 consists of 2,4-Dinitroanisole (DNAN) (31.7%), 3-Nitro-1,2,4-triazol-5-one (NTO) (53%) and 1,3,5-trinitro-1,3,5-triazine (RDX) (15.3%). The difference between IMX-101 and IMX-104 is the subtraction of NQ and the addition of RDX. “IMX-101 and IMX-104 are characterized by low sensitivity toward impact, friction, and electrostatic discharge and generally show high thermal stability and comparable explosive properties to legacy explosives.” [14]

MCX-6100

MCX-6100 is the same composition as IMX-104 with similar output characteristics. MCX-6100 consists of 2,4-Dinitroanisole (DNAN) (32%), 3-Nitro-1,2,4-triazol-5-one (NTO) (53%) and 1,3,5-trinitro-1,3,5-triazine (RDX) (15%)



Figure 8- IMX-101 constituents [27]

CASING

The casing of an artillery shell is made from mild steel. Mild steel is used due to the extreme forces experienced during launch, flight and impact. "Artillery projectiles are subjected to a similar acceleration profile, with a duration of approximately 10 ms and a peak of 15,000 g's" [15] 155mm Artillery shells can have up to 2000 lethal fragments projected across the impact area. [16] The table below shows that these fragments can reach out to over 1500ft. [17]

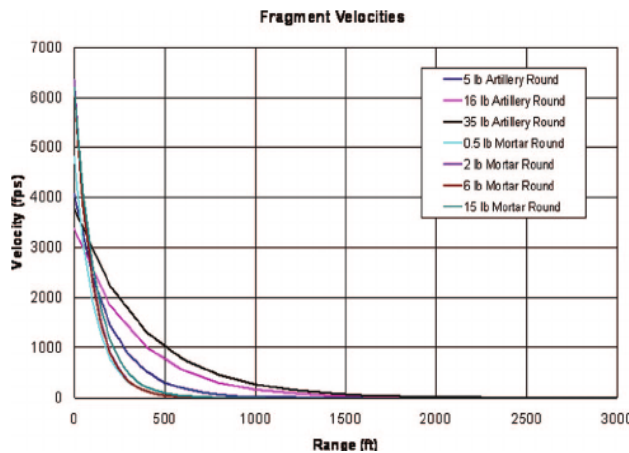


Figure 10- Typical fragment velocities [17]

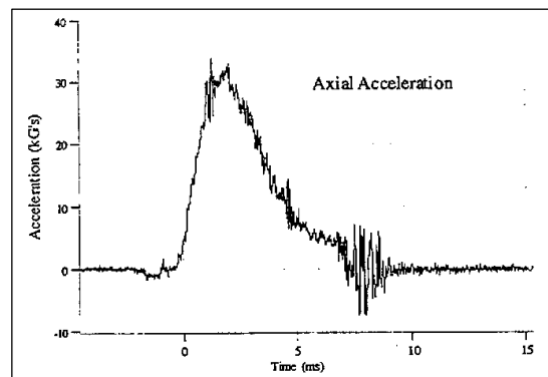


Figure 9- Tank gun acceleration profile [15]

ROTATING BAND

The rotating band on an artillery shell is often called a driving band. This is made from a soft metal commonly copper. This obturates the rear of the barrel stopping any gasses going rearwards and engages the shell in the rifling to allow for spin stabilization.



Figure 11- Recovered rotating bands [18]

CARTRIDGE CASE

The cartridge case is located at the rear of the munition. This is what contains the propellant used to expel the round from the artillery piece. On some systems the use of the cartridge case has been removed and replaced with just the same propellant but contained in bags. The cartridge case is normally brass. This due to the ease of manufacturing and the relative high forces it can withstand during firing. Due to the malleability of the brass this can also act as a seal and help direct the gasses forwards and obturation rearwards.

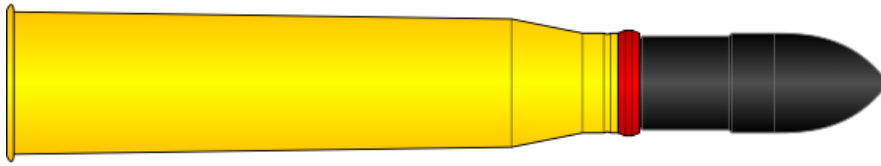


Figure 12- Fixed artillery round [19]

PRIMER

The primer is located at the rear of the artillery shell. This can also be a separate cartridge in certain systems. In artillery systems the percussion cap will ignite the primer once struck. This will allow for the flash to ignite the propellant in a uniform fashion, creating a uniform, repeatable burn rate. This is achieved by flash holes located along the length of the tube and propellant. Examples of primer composition include lead styphnate, lead azide, mercury fulminate and tetracene. [20]



Figure 13- KV-5-U primer cart [28]

PROPELLING CHARGE

The propelling charge is what is used to deliver the shell to the desired location. This can be stored in the cartridge case as discussed above or in bag charges. Bag charges reduce the logistics (G4) requirement for storage and transportation to theatre. Bag charges also allow for incremental use of the propellant and reduce the need to do this through elevation of the artillery piece and complex fire control system calculations. Propellants used in artillery systems normal fall under the category of single, double or triple base propellant. Single base propellant contains just one source, this is

nitrocellulose. Double base propellant contains nitrocellulose and nitroglycerin. Triple base propellant contains nitrocellulose, nitroglycerin and nitroguanidine. These can have a variety of geometry's ranging from stick propellant to granular.

Additives have been added to the propellant to increase life of the barrel through de coppering agents such as bismuth nitrate. Muzzle flash which is an unfortunate product of all propellants is reduced by additives such as potassium nitrate and potassium chloride. Wear reduction additives such as titanium dioxide can be added to extend the life of the barrel. [21]

Previously un used bag charges would just be burnt at the end of the day. The modular charge system minimises wastage which in turn saves money and protects the environment. "In the past charges were open burned directly on the soil surface, which led to the accumulation of 2,4-dinitrotoluene, nitroglycerine and lead in the surface soil" [22]



Figure 15- Modular charge system [23]



Figure 14- Bag propelling charge [29]

STORAGE AND TRANSPORTATION

Transportation and storage is vitally important when designing and procuring munitions for a number of reasons; existing supply chains and storage facilities may be able to be used as the design or modification of a facility could be costly to the purchaser. In addition soldiers on the front line need to be able to rely on the supply chain to provide the munitions and fire power when required. This applies to both operational settings and during peacetime at Defence Munition sites such as MOD KINETON. Conforming to UK MOD DSA regulations. If possible the munition should be within the "normal" storage conditions without diurnal cycling. "Normal" storage conditions will be dictated by manufacturer recommendations.

Research is ongoing regarding classing some insensitive munitions as hazard division 1.6. Division 1.6- "comprises extremely insensitive articles that do not have a mass explosion hazard. HD 1.6 includes those articles which contain only extremely insensitive detonating substances and which demonstrate a negligible probability of accidental initiation or propagation as assessed at Test 7 of AASTP-3. The risk from articles of HD 1.6 is limited to the explosion of a single article." [24] This would reduce the logistical and transportation burden massively and completely change the way we plan and construct explosive sites.

CONCLUSION

Safety features have been discussed in depth above individually, these are vitally important. Only once all these features have been integrated into the munition and artillery piece do you have a safe system. A systems engineering approach is vital for a safe design and product. One example of this is the fuze experiencing the correct centrifugal forces in order to move a shutter out of the way. This is determined by the rifling of the barrel. Getting this wrong can have catastrophic consequences.

Alternative fills are becoming more and more prevalent due to insensitive munition requirements. This will make future operations safer and reduce accidents involving a large array of munitions not just artillery. As production increases the price will drop considerably. The logistic chain will be able to be more adaptable and this will also have a knock on affect for infrastructure requirements both permanently in the UK and when on operations. Further research needs to be done into insensitive munitions to enable the UK to fully exploit the capability. Once this is done focus should turn to the UK manufacturing capability. With the UK market falling 3.6% per year on average between 2017 and 2022 [25]. The current Ukraine conflict will likely force the industry to grow once again.

REFERENCES

- [1] K. Kautzsch, V. Koch, J. Pannhorst and R. Kaden, *Programmable artillery fuse*, 2002.
- [2] E. K. Anderson, C. Chiquete, R. I. Chicas and S. I. Jackson, "Detonation Performance Experiments, Modeling, and Scaling Analysis for Pentaerythritol Tetranitrate (PETN) High Explosive," Wiley-VCH GmbH, 2022.
- [3] Army Ammo Data Sheet, "Fuzes Class A Explosives Dodac Na," [Online]. Available: <https://www.bevfitchett.us/army-ammo-data-sheet/fuzes-class-a-explosives-dodac-na.html>. [Accessed July 2023].
- [4] E. L. Baker, M. R. Andrews and K. M. Jaansalu, "L-261 TNT Exudation, Crystal Growth and Ageing," Munitions Safety Information Analysis Center, 2020.
- [5] J. P. Agrawal, "Processing and Assessment Techniques for Explosives," in *High Energy Materials: Propellants, Explosives and Pyrotechnics*, John Wiley & Sons, 2010, p. 164.
- [6] "The Climate in Afghanistan," [Online]. Available: <https://www.worlddata.info/asia/afghanistan/climate.php>. [Accessed July 2023].
- [7] United States Environmental Protection Agency , *Technical Fact Sheet- 2,4,6- Trinitrotoluene (TNT)*, 2014.
- [8] B. W. Thorpe and M. A. Parry, "INFLUENCE OF HNS ON THE MICROSTRUCTURE," DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION, 1981.
- [9] E. L. Baker, "LARGE CALIBER PROJECTILE FILL," Munition Safety Information Analysis Center, 2019.
- [10] E. L. Baker and M. W. Sharp, "Gun Launch and Setback Actuators," 2018 Insensitive Munitions & Energetic Materials Technology Symposium, 2018.
- [11] S. H. A. F. (Ret), "The Propaganda Shell," [Online]. Available: <https://www.psywarrior.com/PropArtilleryShell.html>. [Accessed July 2023].

- [12] A. L. Kuhl, J. Chandler, A. K. Oppenheim, R. Spektor and R. E. Ferguson, "Confined Combustion of TNT Explosion Products in Air," 1998.
- [13] US Army, "Common Low-cost IM Explosive Program," US Army, 2011.
- [14] D. Frem, "A Review on IMX-101 and IMX-104 Melt-Cast Explosives: Insensitive Formulations for the Next-Generation Munition Systems," *Propellants, Explosives, Pyrotechnics*, vol. 48, no. 1, 2023.
- [15] M. S. Berman, "Electronic Components for High-g Hardened Packaging," 2006.
- [16] United Nations, "Explosive Weapons- Unguided Artillery Shells," 2014. [Online]. Available: https://www.ohchr.org/sites/default/files/Documents/HRBodies/HRCouncil/CoIGaza/Explosive_Weapons.pdf. [Accessed July 2023].
- [17] H. R. Champion and J. B. Holcomb, "Injuries From Explosions: Physics, Biophysics, Pathology, and Required Research Focus," *The Journal of trauma*, 2009.
- [18] J. Z. J. Q. Z.-q. Z. K.-b. Y. X.-l. C. L. H. K.-s. Z. & R.-g. C. Bin Wu, "Preparation of the projectile rotating band and its," *Journal of Adhesion Science and Technology*, p. 1145, 2016.
- [19] C. Ankerstjerne, "German Ammunition Nomenclature," June 2023. [Online]. Available: <https://panzerworld.com/german-ammunition-nomenclature>. [Accessed July 2023].
- [20] K. D. Oyler , N. Mehta and G. Cheng, "OVERVIEW OF EXPLOSIVE INITIATORS," Picatinny Arsenal, New Jersey, 2015.
- [21] R. Hasenbein, "Wear and Erosion in Large Caliber Gun Barrels," U.S. Army Armament Research, Development & Engineering Center .
- [22] S. Thiboutot, G. Ampleman, D. Pantea, S. Whitwell and T. Sparks, "Lead emissions from open burning of," Canadian Crown, 2012.
- [23] Rheinmetall, "155 MM ARTILLERY MODULAR CHARGE SYSTEM," [Online]. Available: <https://www.rheinmetall.com/en/products/propellants/propulsion/artillery>. [Accessed July 2023].
- [24] Defence OME Safety Regulator, *DSA 03.OME Part 2 (JSP 482) -*, Defence Safety Authority, 2019.

- [25] IBIS World, "Explosives Manufacturing in the UK - Market Research Report," 2023.
]
- [26] PubChem, 2,4,6-Trinitrotoluene, National Library of Medicine.
]
- [27] P. Gong and K. B. Donohue, "Comparative toxicogenomics of three insensitive munitions constituents 2,4-dinitroanisole, nitroguanidine and nitrotriazolone in the soil nematode *Caenorhabditis elegans*," *BMC Systems Biology*, 2018.
- [28] Arsenal, "COMPONENTS FOR AMMUNITION- KV-5-U," [Online]. Available:
] <https://www.arsenal-bg.com/c/primers-for-artillery-cartridges-153/kv-5-u-241>. [Accessed July 2023].
- [29] CSG Defence, "PROPELLING CHARGE," [Online]. Available: <https://csgdefence.cz/propelling-charge>. [Accessed July 2023].
- [30] EXPAL, "Field Artillery Munition," [Online]. Available:
] <https://www.expalsystems.com/en/global-solutions/munitions/field-artillery>. [Accessed July 2023].
- [31] CAT UXO, "MD-81 Fuze," [Online]. Available: <https://cat-uxo.com/explosive-hazards/fuzes/md-81-fuze>. [Accessed July 2023].