ISSN No. 0971-4413

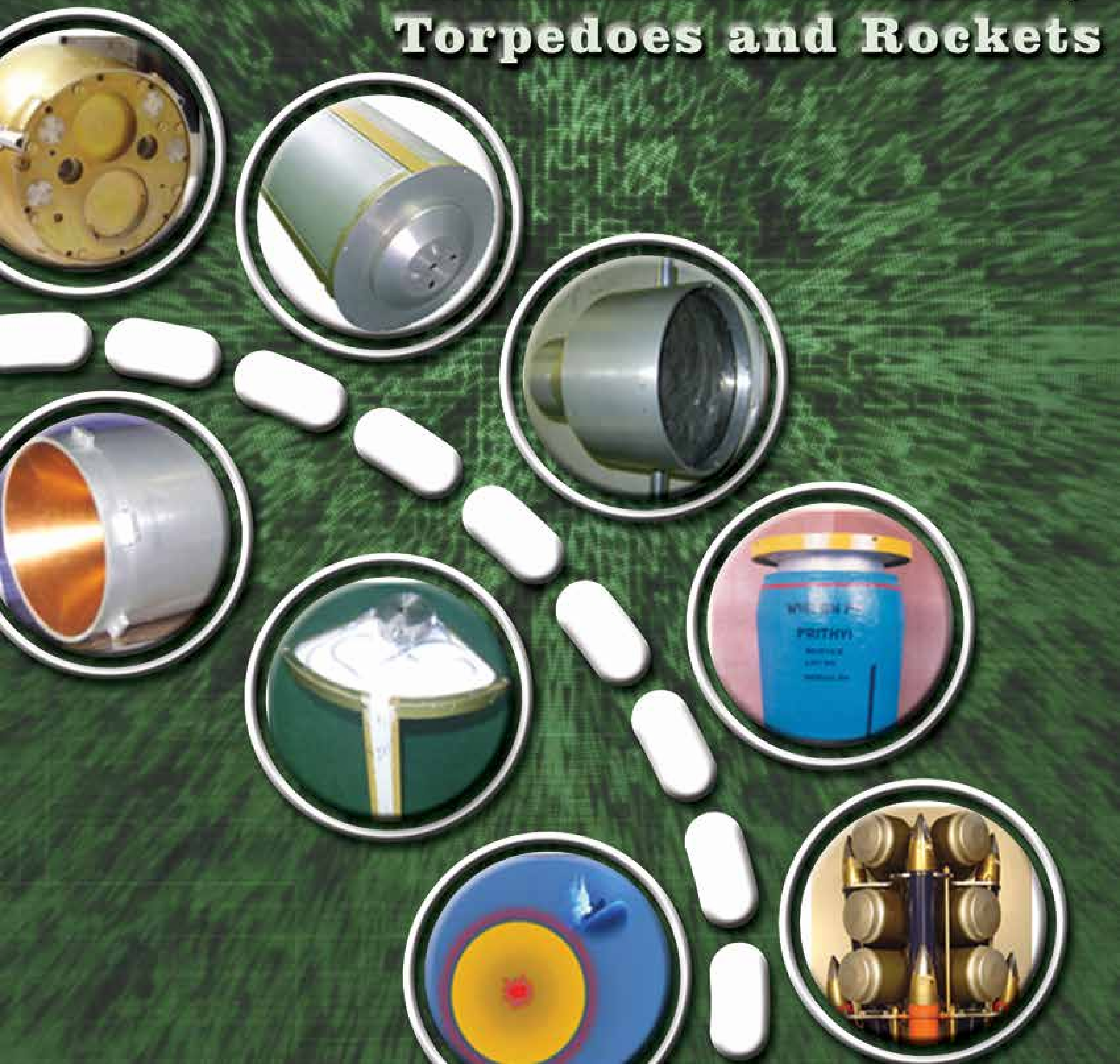
TECHNOLOGY FOCUS

टैक्नोलॉजी फोकस

A bimonthly S&T Magazine of DRDO

Vol. 26 No. 03, May-June 2018

Warhead for Missiles, Torpedoes and Rockets



From the Desk of Guest Editor

Armament Research & Development Establishment (ARDE) is one of the earliest laboratories established under the DRDO umbrella. It has, as its mandate, the design and development of conventional armaments for the Services and Paramilitary Forces. One of the areas in which ARDE has established core competence is the design and development of a variety of warheads and safety arming mechanisms. With its abundant experience, ARDE is contributing this critical element to a variety of weapon platforms such as rockets, missiles and torpedoes.

In the pre-1980s period, development of warheads was done amidst constraints such as limited access to information in the open literature due to classified nature of the topic, absence of interaction among R&D organisations, industry and academia and lack of mathematical models for warhead design. Post 1980, emphasis was on finding solutions for better control of fragmentation patterns and blast effects against critical targets and study and improvement of the shaped charge mechanism for defeat of armoured targets. Indigenous development of preformed fragmentation warheads for Akash and Trishul missile system were major milestones. Development of Dentex explosive and availability of better fabrication facilities resulted in the development of a 1000 kg variable mass prefragmentation warhead for Prithvi missile with complex geometry. ARDE has immensely contributed to the success of the IGMDP by designing and developing a variety of warheads for the missiles. A major technological breakthrough has been the development of submunition warheads for various medium and large calibre missiles, rockets, bombs and artillery systems. An innovative warhead test vehicle has been evolved for test and evaluation. DPICM bomblet, incendiary, prefragmentation and penetration-cum-blast submunitions have been established for warheads for Prithvi missile, Pinaka rocket and artillery rounds. Use of advanced simulation methods and conduct of numerous sophisticated experiments resulted in the successful development of 50 kg shaped charge warhead in anti-submarine role and tandem shaped charge warheads for neutralising MBTs protected with Explosive Reactive Armour (ERA).

To meet the increasing requirement of highly accurate weapons with enhanced lethality that inflict low collateral damage, ARDE has forayed into the cutting edge technology area of directional warheads. Thermobaric warheads containing fuel rich explosive composition which produces blast overpressure as well as heat energy on detonation are being developed by ARDE based on thermobaric composition developed by HEMRL. Tank ammunition using thermobaric composition has also been developed.

Warhead technology development is a complex, multi-disciplinary field. Specialised testing and evaluation facilities are required to visualise the events. Demand for high performance warhead systems is on the increase. Since the present war is fought in urban areas, warheads with higher accuracy and low collateral damage are the need of the hour. ARDE has constantly undertaken technology development activities for advanced warheads. These are aimed at enhancing the performance of conventional warheads. A few of them are high performance shaped charges having low length to diameter ratio, concrete penetrating warheads based on follow through technology and kinetic energy rod warhead against tactical ballistic missile class of targets.

This issue of Technology Focus brings out an introduction on the complex warhead technology and ARDE's contributions towards development of warhead systems for various weapon platforms.

Dr K M Rajan
Distinguished Scientist & Director, ARDE

Warhead for Missiles, Torpedoes and Rockets

After the Defence Research & Development Organisation was created as an inter-service organisation in 1958, the existing Technical Development Establishment (Ammunition) and Technical Development Establishment (Weapons) were reorganised into two separate establishments—Armament Research and Development Establishment (ARDE) to carry out R&D functions, and Chief Inspectorate of Armaments (CIA) to look after the production and inspection functions. These two establishments came into being with effect from 1st September 1958.

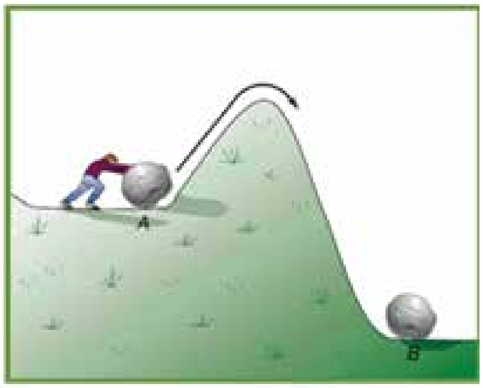
ARDE, Pune is an inter-service establishment catering to the needs of all the three wings of the Indian Armed Forces—army, navy and air force. The philosophy of ARDE is to be of "Service to the Services". The capability of ARDE embraces a whole spectrum of activities related to the complex, multi-disciplinary field of conventional armament technology. These activities comprise basic and applied research and development, prototyping, test and evaluation, modeling, simulation and software development, Transfer of Technology (TOT) and limited scale pilot-plant production of crucial items. A full fledged Pashan Range for test and evaluation, a prototype manufacturing unit for making prototypes for weapon development and modern pilot plants for production of air power cartridges and PZT components are some unique features.

ARDE is an ISO 9001:2008 certified laboratory. Over the years, it has contributed several major weapon systems and sub-systems such as Pinaka Multibarrel Rocket Launcher System, INSAS family of weapons and ammunition, warheads for IGMDP missiles, Arjun armament, Adrushy influence munitions and various categories of aircraft bombs and naval armament. One of the most prestigious programmes of DRDO, namely design and development of a 155 mm/52 Cal Advanced Towed Artillery Gun System (ATAGS) is making rapid strides. ARDE has also taken up several programmes for developing precision guided munitions, some of which are the Guided Pinaka Rocket, Anti-tank Guided Missile for Arjun MBT and 450 kg guided bomb.

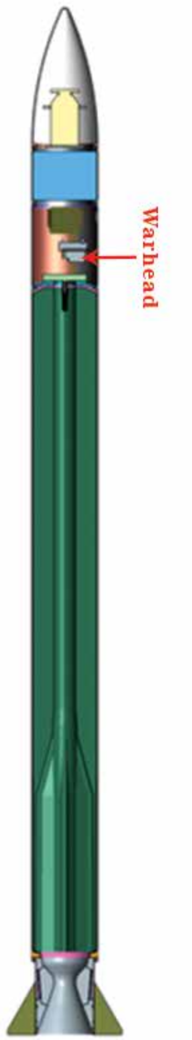
Warheads

Warhead is a specific device or a part of the Armament System which causes desired damage to the target and renders it incapable of performing its intended function. Generally chemical energy contained in high explosives is used to achieve the desired kill effect. There are other sources of high energy such as nuclear sources, high power laser, etc. This issue discusses various technologies involved in conventional warheads containing high explosives.

Explosives are in a meta-stable state, and when suitably initiated, they release large amount of energy in the form of blast, sound and heat. Chemical energy stored in the explosives is converted to kinetic energy of the expanding metallic casing and gases. When these gases and metallic fragments interact with targets with energy levels much exceeding their strength, the targets collapse. Explosives detonate when suitably initiated. Detonation is a violent decomposition of explosive, releasing large amounts of heat and



Explosives are in metastable state



Typical missile and warhead location

pressure in a very small duration of time. Pressures ranging from 300-400 kbar are produced during detonation. Rate at which detonation progresses in the explosive is supersonic. Damage to the target could be classified as any one or more of the following:

◊ Physical

◊ Thermal

◊ Radioactive

◊ Biological

◊ Chemical

◊ Psychological

Specific energy of some energetic materials

Petrol: 46 MJ/Kg

Coal: 24 MJ/Kg

TNT: 4.2 MJ/Kg

Though specific energy is relatively less for some explosives, rate of release of energy is much higher, thereby rendering them useful in warhead applications.

Elements of Warhead System

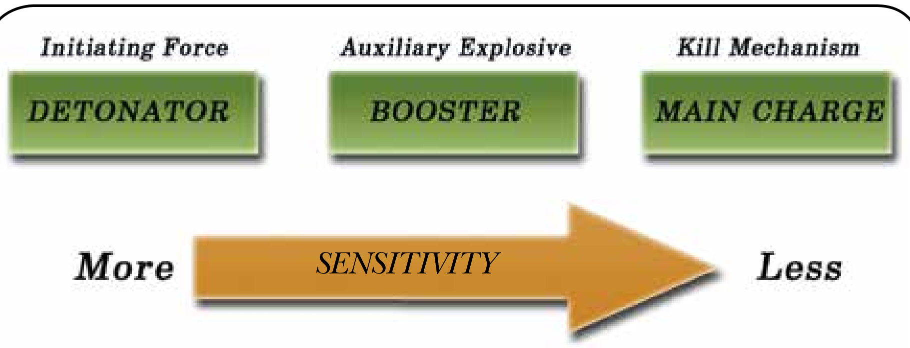
Warhead system consists of three major elements. They are:

◊ Kill mechanism

◊ Fuzing mechanism

◊ Safety arming mechanism

Kill mechanism contains the energetic material. Fuzing mechanism senses the environments for locking or unlocking various safety interlocks. Safety arming mechanism is the element which houses the initiator and detonates the warhead on receiving appropriate signals from fuzing mechanism. All these elements make up what is known as the explosive train. The explosive train is a series of actions designed to initiate detonation through a given sequence, and is a combination of primary and secondary explosives.



Explosive Train

Design of Warhead System

Design of warhead is dictated by various factors as follows:

◊ Type of target and its characteristics like size, hardness, vulnerability, nature of kill

◊ Characteristics of carrier/delivery system like probability of hit/near miss

◊ Technology status in explosives, materials and their agglomeration

Design of warhead involves understanding of multi-disciplinary fields such as:

◊ Chemistry and engineering of explosives

◊ Detonics

◊ Safe/arm technologies

◊ Fuzing technologies

◊ Explosive-casing material interaction studies

◊ Interaction of kill mechanism and target

◊ Target failure phenomenon

Classification of Warheads

Within the ambit of general definition given in the previous sections, warheads can be categorised into different classes based on the source of energy contained in them. For example :

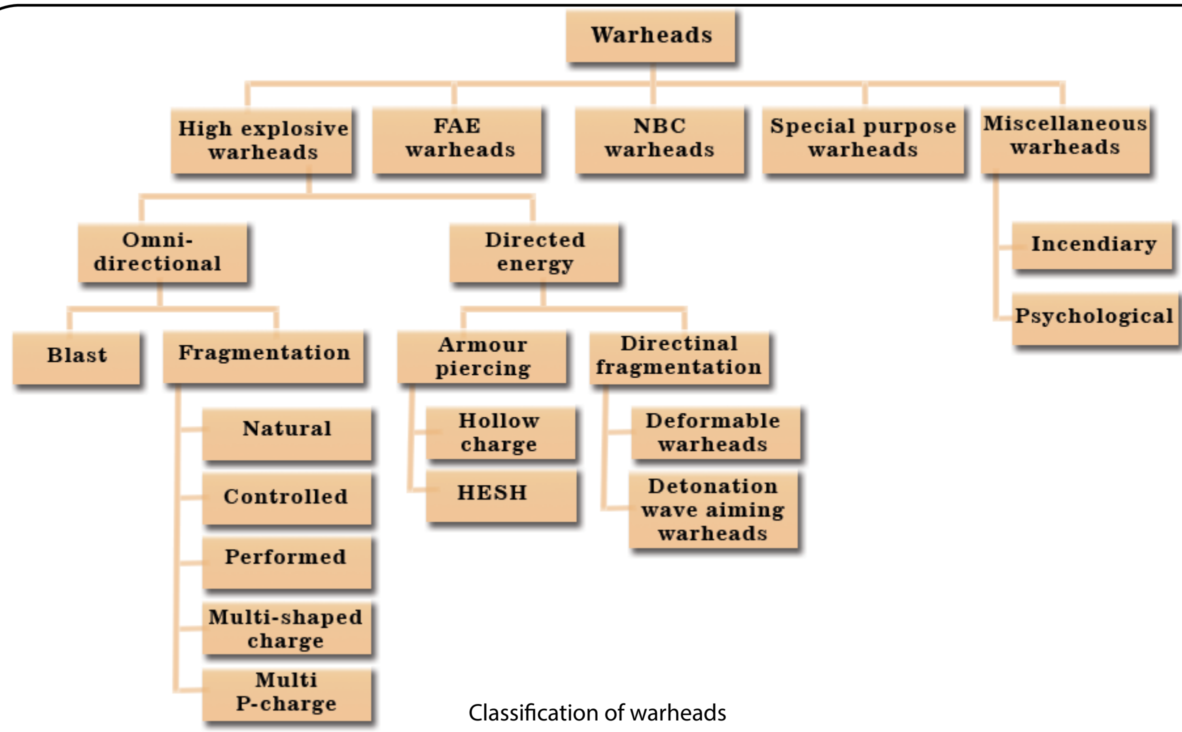
◊ High explosive warheads

◊ Fuel air explosive warheads

◊ Nuclear, biological and chemical warheads

Conventional high explosive warheads can be further classified into omni-directional and directed energy warheads. General classification of warheads is given in the following chart. This is not an exhaustive listing.

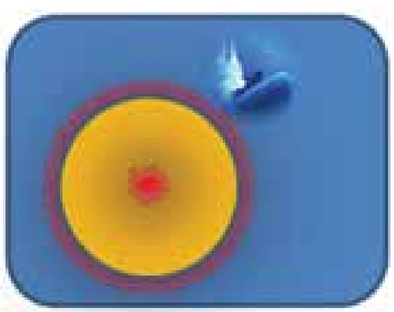
Innovative designs intended to optimise delivery of energy onto the target has resulted in different kinds of kill mechanisms. However, the basic mechanism will fall in one of the categories mentioned in the chart.



Classification of warheads

Omni-Directional Warheads

Omni-directional warheads have an isotropic pattern of energy distribution around the point of burst. They can be either blast warheads or fragmentation warheads. Blast warheads use the explosive air shock and resulting overpressure to cause damage to the target. In case of fragmentation warheads, explosive energy is used to expand a metal casing into a number of small fragments. Fragments can be formed either by natural fragmentation process or controlled fragmentation process. Preformed fragments can also be arranged on the surface of the explosive column. These fragments accelerate to a great speed under explosive action carrying the kinetic energy to longer distances. Two variants of omni directional fragmentation warheads are discrete rod warheads and continuous rod warheads. They use rod type elongated fragments in large numbers to inflict higher penetration in target as compared to conventional spherical or cubical fragments.



Omni-directional warhead

Directed-Energy Warheads

Directed-energy warheads are designed to direct part of the energy in a specific direction. Various mechanisms are evolved to direct explosive energy. Shaped charges are mechanisms wherein the explosive energy is focused by the use of a cavity lined with a metal. Nearly 15-20 per cent of the explosive energy is focused towards one direction by the collapse of this lined cavity. Explosive energy can also be directed in a specific direction by various other methods as employed in detonation wave aiming warheads and deformable fragmentation warheads. This involves detonating a cylindrical warhead peripherally along a line in such a way that more explosive energy is directed to one side than to other sides.

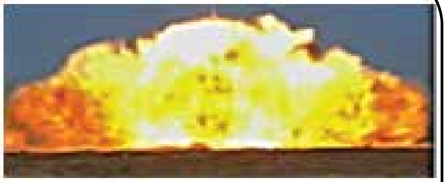
Directional warhead

Fuel Air Explosive Warheads

Fuel Air Explosives (FAE) are oxygen deficient high energy materials. These chemicals are dispersed in air over the target area using a suitable delivery and dispensing mechanism to form an aerosol cloud. This cloud is then detonated to deliver the intense blast energy onto the targets.

Warhead before detonation

Aerosol cloud formation



Aerosol detonation

FAE Warhead functioning

Types of Kill Mechanisms

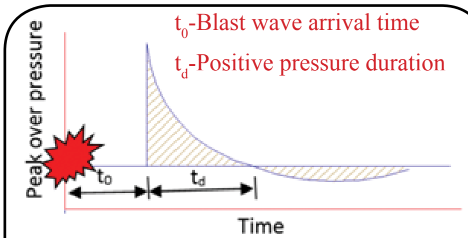
Kill mechanisms based on high explosives have been categorised into five types as follows:

- ◊ Blast charges
- ◊ Fragmentation charges
- ◊ Shaped charges
- ◊ Projectile charges
- ◊ Flat cone charges

Underlying mechanism in all the above types is same and that is conversion of chemical energy contained in the high explosive to mechanical energy in the form of either kinetic energy or blast pressure energy.

Blast Charges

These are simply high explosives contained in a thin casing made of metals or non-metals. When the explosive contained in the casing is detonated, due to the sudden release of energy, high pressure waves are generated with the evolution of large amount of gaseous products. Energy contained in the blast waves are responsible for the kill of target.



A typical blast wave profile

Fragmentation Charges

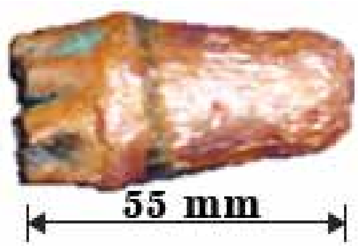
Fragmentation charges are similar to blast charges and the energy liberated on detonation of the explosive is carried by the high density fragments surrounding the explosive column. These fragments are lethal at even large distances and typically employed against soft skinned targets.

Shaped Charges

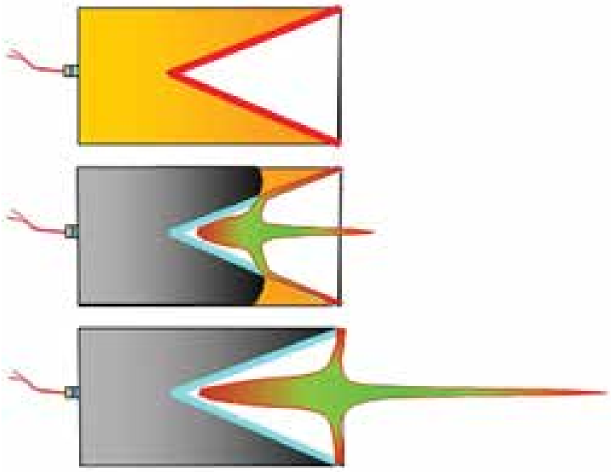
Shaped charge consists of a cylindrical explosive charge having a conical cavity on one end generally lined with a metallic liner and detonated on the opposite side exactly along the axis of liner. On detonation of shaped charge, high pressure detonation wave sweeps across the liner surface. Pressure in the detonation wave is typically over a million atmosphere and strength of the metallic liner is nearly negligible when it encounters such high pressures. Liner collapses hydrodynamically onto the axis and further forms into a hyper velocity jet. This hyper velocity jet made of high density material penetrates the targets hydrodynamically owing to its large kinetic energy associated with it.

Projectile Charges and Flat Cone Charges

These are variants of shaped charge in which the geometry of metallic liner is altered to obtain either a projectile or a short metallic jet moving at high velocities.



Explosively formed projectile



Shaped charge jet formation

Various Targets and Types of Warheads Meant to Defeat Them	
Targets	**Type of Warheads**
Soft skinned vehicles, parked aircraft in open, personnel, aircraft and missiles	Fragmentation warheads
Armour protected combat vehicles, Main Battle Tanks (MBT)	Shaped charge and explosively formed projectile warheads
Bunkers, runways, administrative buildings, concrete protected targets	Penetration-cum-blast warhead
Petrol oil lubricant dumps, personnel in open, railway marshalling yards, etc.	Incendiary warheads
Underwater targets like submarines, light concrete buildings, personnel in open	Blast warheads

Penetration-cum-Blast Warheads

Penetration-cum-Blast (PCB) warheads are a class of warheads used against concrete protected structures. These are generally ogive shaped projectiles containing explosives intended to breach the concrete protection and then burst. The laboratory has developed PCB warheads of different mass category for variety of missiles and ammunition.

Submunition Warheads

In this type of warhead, the mother warhead holds the submunitions till the desired point in the flight and dispenses them over the target area. Several types of submunition warheads have been developed using base ejection for 120/155 artillery rounds and low calibre rocket systems. The design of submunition warheads for medium and large calibre rockets and missiles had been a challenge to the designer for quite a long time.

The development of low charge linear shaped charge technology, milligram level pyro-cartridges, accurate electric sequencers have resulted in successful development of airframe opening mechanisms for medium calibre rockets and missile systems.

To achieve a wide area coverage, a two stage ejection system has been developed. An innovative technique of warhead test vehicle has been evolved with combined efforts of warhead and missile designers. In this technique, the warhead is carried by a helicopter to a higher altitude and released. A parachute is used to stabilise the system. To achieve near terminal conditions, the warhead is boosted by a rocket motor after release.

Dual purpose improved conventional bomblet, incendiary, prefragmentation and penetration-cum-blast submunitions have been established for development of various warheads for Prithvi missile, Pinaka rocket and Artillery rounds.

Warheads Developed for Various Weapon Systems

Warhead technology has passed through an evolutionary process starting from empirical studies to high end simulation and sophisticated testing. ARDE has been the nodal lab for the development of various warheads for guided missiles, artillery rockets, torpedoes, etc.

High Energy Materials Research Laboratory (HEMRL), Pune provides necessary support for the development and processing of explosives. Large scale testing and performance evaluation are carried out at Terminal Ballistics Research Laboratory (TBRL), Chandigarh and Proof and Experimental Establishment (PXE), Balasore. Many spin-off technologies have been established during the development of warheads. Glimpses of different types of warheads developed by the laboratory for various weapon systems and associated technologies developed are given in the following sections.

Fragmentation Warheads

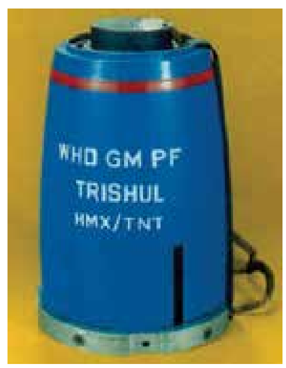
Technologies Developed

- ◊ Development of HEMEX-high density, high shock insensitive, fuel rich explosive
- ◊ Development of high explosive-DENTEX optimised in terms of Velocity of Detonation (VOD) and blast effects
- ◊ Testing and evaluation methodologies
- ◊ Fabrication of metallic casings with internal/external notching through investment casting, hot forming and machining
- ◊ High density Tungsten alloy fragments using powder metallurgy technique
- ◊ Shock impedance mismatch technique for preventing spallation of fragments with high charge to metal mass (C/M) ratio
- ◊ Variable Mass Preformed Fragmentation (VMPF) concept for achieving uniform lethality and improved hit density
- ◊ Mathematical models which can accurately predict the performance, viz., spatial distribution and lethality

Products Delivered

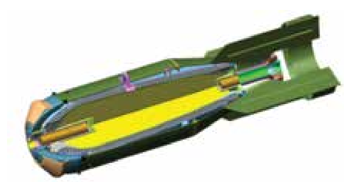
1000 kg PF Warhead-Prithvi

500 kg PF Warhead-Prithvi



15 kg PF Warhead-Trishul

65 kg PF Warhead-Akash



125 kg PF Air delivery bomb

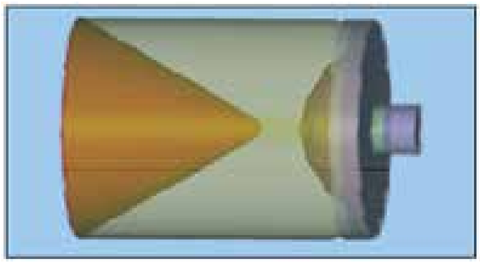
300 kg Natural fragmenting warhead-PJ-10

Shaped Charge Warheads

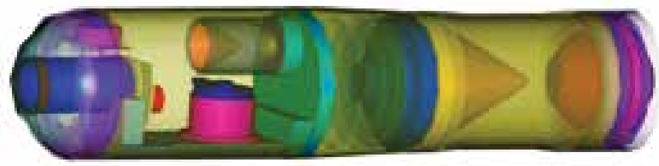
Technologies Established

- ◊ Development of Oxygen Free Electronic (OFE) grade Copper
- ◊ Establishing flow forming for manufacturing precision liners
- ◊ Design and development of wave shaper technology
- ◊ Design of precision initiation couplers
- ◊ Explosive machining for precision shaped charge warheads
- ◊ 1D mathematical and 2D simulation for performance prediction
- ◊ Development of pressure casting technology for explosive filling
- ◊ Tandem shaped charge warhead against Explosive Reactive Armour (ERA) protected armour

Products Developed



8 kg Main warhead-NAG/ SANT/HELINA



Tandem warhead-NAG

50 kg Warhead-light weight torpedo

10 kg Warhead-missile launched PGM

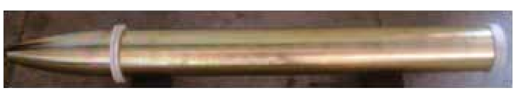
Explosive machining

Flow forming facility

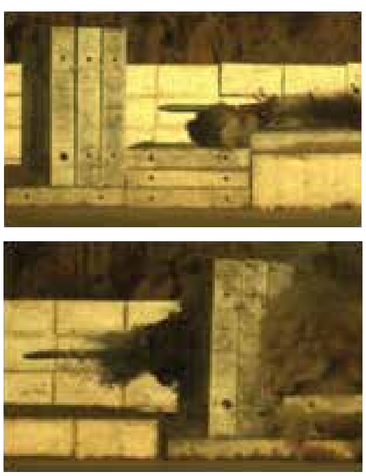
Penetration-cum-Blast Warheads

Technologies Established

- Development and validation of design codes
- Established concrete penetration models
- Development of shock insensitive explosives
- Kill mechanisms of 10 kg to 300 kg class
- Test and evaluation methodologies



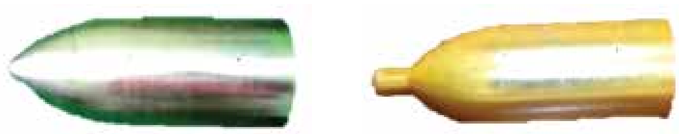
80 kg PCB Warhead-Smart Anti-Airfield Weapon (SAAW)



Rail Track Rocket Sled (RTRS) test penetration performance-SAAW warhead

Products Developed

450 kg High Speed Low Drag (HSLD) bomb



10 kg Missile Launched PGM (MLPGM) warheads

120 mm PCB ammunition

300 kg PCB warhead- Nirbhay

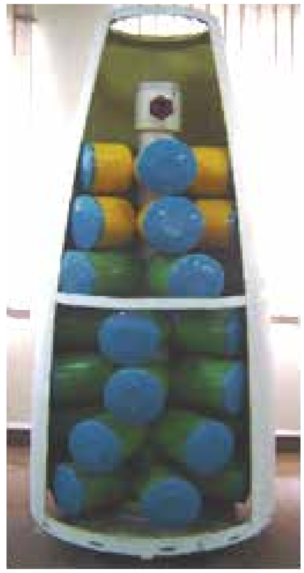
Submunition Warheads

Technologies Established

- ◊ Development of nose cone opening mechanism
- ◊ Power cartridge assisted ejection mechanism
- ◊ Development of single and two stage ejection mechanisms
- ◊ Light weight dispensation mechanism for runway denial penetrating submunition warhead
- ◊ Rocket assisted ejection mechanism
- ◊ Hot gas operated flap opening mechanism
- ◊ Development of Electronic Safety and Sequencer Unit (SASU)
- ◊ Evolution of WHTV test methodology for evaluating warhead performance

Warhead Test Vehicle (WHTV) test

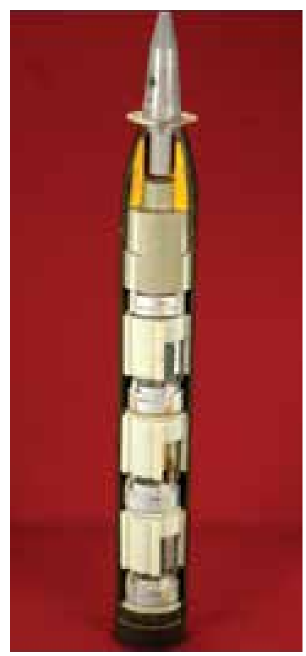
Products Developed



1000 kg Submunition bomblet warhead-Prithvi

500 kg Composite warhead-Prithvi

500 kg RDPS warhead-Prithvi



Submunition warhead-Pinaka

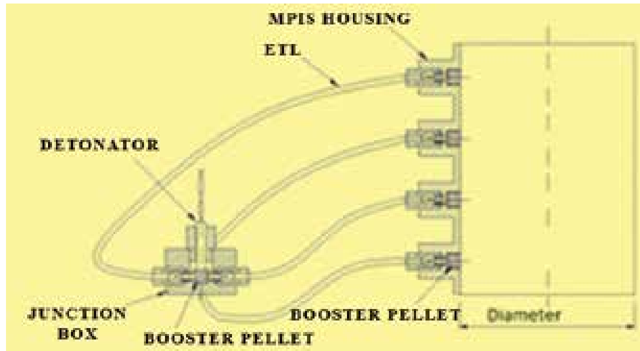
Current Developments

The requirements of modern weapon systems are high accuracy and enhanced lethality, while causing minimum collateral damage. This has opened up a great challenge to weapon designers. Warhead designers face severe mass and volume constraints, with a need to configure the warhead in a compact space and at the same time performance aspects are not compromised. To achieve this, designers are looking at directional warheads and high performance warhead systems. Better explosive compositions having high specific energy are being experimented.

Directional Warheads

Blast and fragmentation effects of a point initiated conventional warhead are isotropic in nature around point of burst. In such a scenario, the sector in which the target lies receives only a proportionate share of such effects and the remainder is wasted without producing any appreciable effect on the target. Directional warhead involves altering the detonation wave in such a way that more explosive energy is directed towards the target as compared to other sides, thereby enhancing the effectiveness of the warhead.

There are different methods to achieve directionality. The laboratory has developed directional warheads for various applications. Some of the developments in the field of directional warheads are :



Directional blast warhead configuration

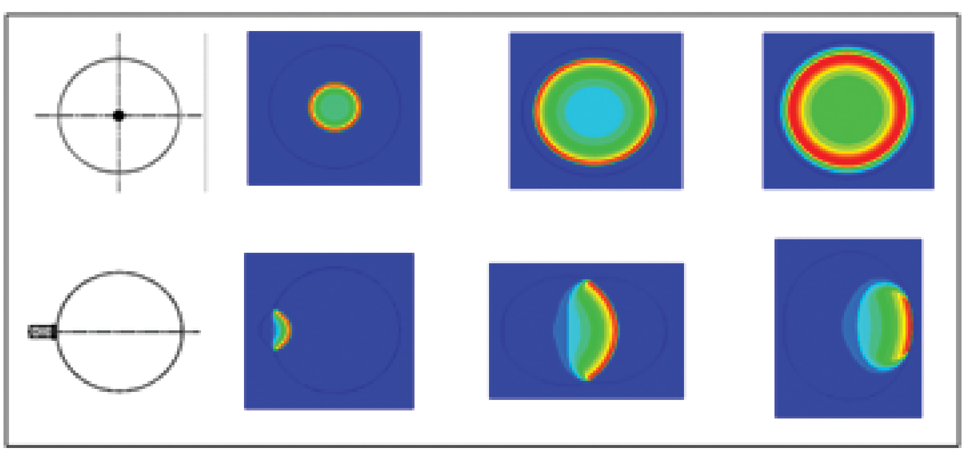
Detonation Wave Aiming Warheads

The laboratory has configured a 50 kg directional blast warhead for underwater applications. This concept involves initiating the warhead eccentrically along a line on the periphery in such a way that more explosive energy is directed towards one side.

Multiple lines of initiators are provided on the periphery so that desired line can be initiated based on the end game requirements. This is based on the principles of detonation wave aiming towards the intended direction.

Critical subsystem of a directional warhead in which detonation geometry is altered is a Multipoint Initiation System (MPIS). MPIS consists of equal length Explosive Transfer Lines (ETLs) and a junction box where these ETLs are terminated at a single point.

Compact MPIS



Concept of directional blast

50 kg Directional warhead

Detonation initiated at the junction box is transferred to multi points on the warhead periphery through ETLs. Warhead is initiated at all the points simultaneously to give directionality. There are multiple lines of initiation on the warhead periphery. According to the endgame requirements, required line is chosen and initiated so that maximum energy is directed towards the target.

Directional warhead thus configured for underwater applications enhances blast overpressure by 40 per cent as compared to conventional point initiated warhead. Along the same lines of directional blast warhead, the concept has been successfully adapted in the case of a fragmentation warhead. Twenty per cent increase in fragment velocity has been obtained in this design as compared to an omni -directional warhead.

40 kg FG Warhead for exo-atmospheric interception

Fragment Generator Warheads

Fragment Generator (FG) warhead is a kind of forward firing warhead wherein premade fragments are arranged on one face of the warhead which is backed by suitable thickness of high explosive and is initiated from the opposite end. These type of warheads are commonly employed against targets such as tactical ballistic missiles where total structural kill is required and to achieve it, a highly dense fragment cloud is needed.

A 40 kg FG warhead has been test evaluated both in static as well as in flight condition and it has performed as per expectations. As it is pertinent that the line of fire of a forward firing warhead needs to be directed towards the target, a Pyro-Based Orientation Mechanism (PBOM) has been developed which provides one axis gimbal (Azimuth gimbal) of the warhead. It is a piston-cylinder based system powered by the hot gases generated on initiation of pyro-cartridges. It is capable of orienting the fragmenting face of warhead in three fixed positions within a few milliseconds.

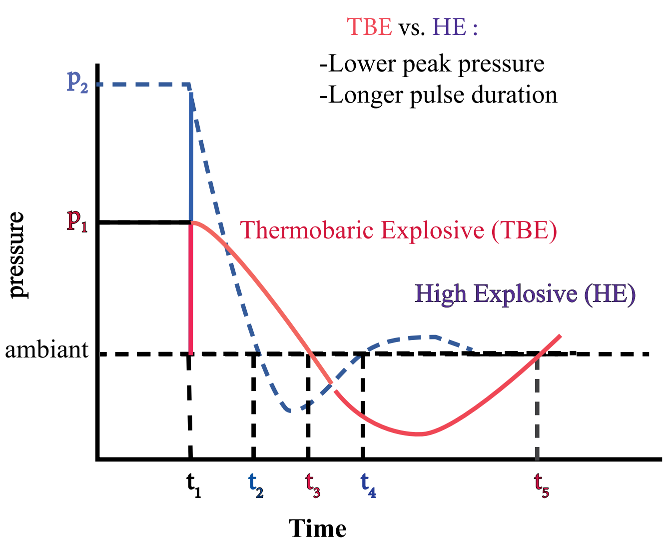
80 kg FG Warhead for endo-atmospheric

Thermobaric Warheads

Thermobaric warheads contain fuel rich explosive composition called thermobaric explosive. As the name implies, this composition on detonation produces blast overpressure as well as heat energy lasting for a few 100s of milliseconds. These warheads are used against soft targets like personnel in open and concrete protected targets. Thermobaric explosive compositions contains metallic fuel in excess generally fine aluminium. Post detonation reaction of this aluminium with atmospheric oxygen is exothermic in nature and produces large amount of heat energy.

The laboratory has designed various warheads and tank ammunition based on thermobaric composition developed by HEMRL. Effectiveness of these warheads has been tested against various simulated targets.

Pressure history of High Explosive (HE) and Thermobaric Explosive (TBE) detonations



120 mm TB ammunition

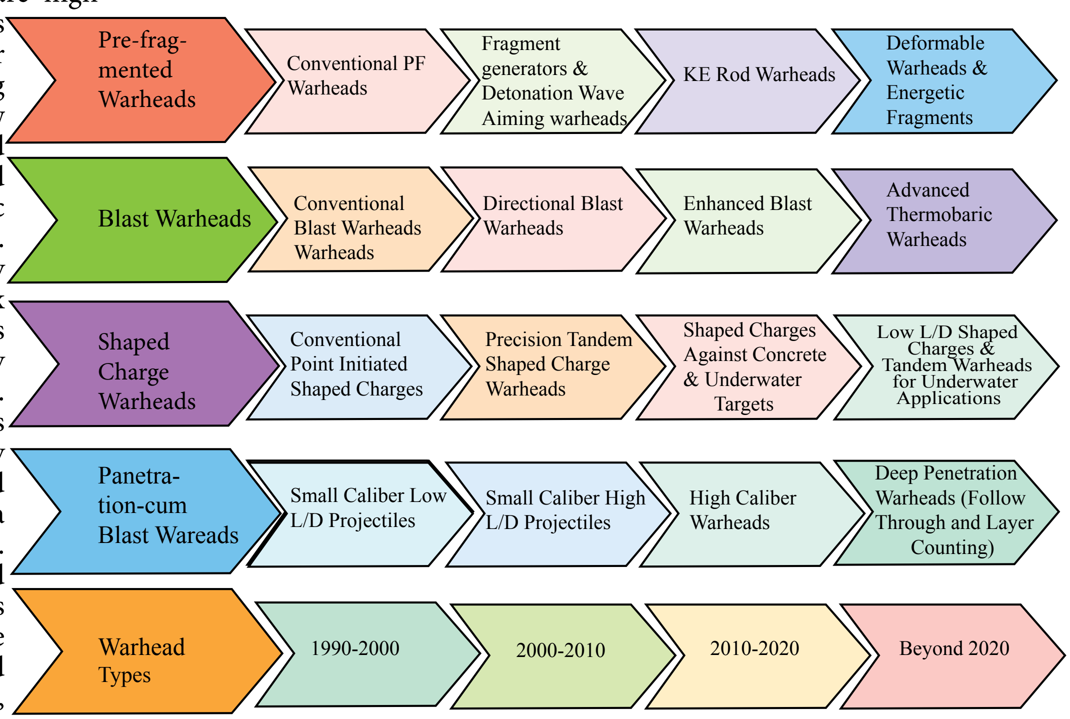
Sequence of events of dynamic testing of thermobaric ammunition

Detonation of thermobaric ammunition on RCC block – Effect on target

Dynamic tests and target effects–120 mm TB Ammunition

Future Plans

ARDE has undertaken several technology development activities on advanced warhead development. These are aimed at enhancing the performance of conventional warheads. A few of them are high performance shaped charges having low length to diameter ratio, concrete penetrating warheads based on follow through technology and kinetic energy rod warhead against tactical ballistic missile class of targets. Warhead technology development is complex in nature owing to various factors. Warhead technology is a multi-disciplinary field. Knowledge in various fields is essential to effectively design warheads. Warhead mechanism is an ultra high speed phenomenon. specialised testing and Evaluation requirements are required to visualise the events. As warhead technology advances, protection levels are also improving. Hence demand for high performance warhead systems is increasing. Since the present war is fought in urban areas, collateral damage needs to be minimum. Future requirement is warheads with higher accuracy and low collateral damage.



Future technology development plans

Warheads at a Glance

Weapon System	Warhead Type	Weight Class
Prithvi	Pre-fragmented Runway denial penetration submunition DPICM bomblet Incendiary submunition	1000 kg and 500 kg
Akash	Pre-fragmented	55 kg
Trishul	Pre-fragmented	15 kg
Anti-tank Guided Missiles ATGM-NAG/ HELINA /SANT	Tandem shaped charge	8 kg
Advanced light weight Torpedo	Shaped charge	50 kg
Smart Anti Air field (SAAW) air delivered bomb	Penetration-cum-blast	80 kg
Subsonic cruise vehicle-Nirbhay	Penetration-cum-blast	300 kg
Astra	Pre-fragmented	15 kg
Artillery rocket-Pinaka	Pre-fragmented DPICM subminition Soft target submunition Anti-tank submunition	100 kg
AAD Interceptor	Pre-fragmented	80 kg
PAD Interceptor	Pre-fragmented	40 kg
Prahaar	Pre-fragmented	200 kg
BrahMos	Antiship (Blast and naturally fragmenting)	200 kg
Quick Reaction Surface to Air Missile (QRSAM)	Pre-fragmented	32 kg
New Generation Anti-radiation Missile (NGARM)	Pre-fragmented	60 kg
Pralay	Pre-fragmented Penetration-cum-blast	350 kg and 700 kg
High Speed Low Drag (HSLD) Bomb	Penetration-cum-blast	250 kg and 450 kg
Air delivered bombs	Pre-fragmented	500 kg, 250 kg and 125 kg

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Editors acknowledge the contribution of Shri S. Harikrishnan, Scientist F of Armament Research & Development Establishment (ARDE), Pune in preparing this issue.

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DESIDOC Publications

Published by DESIDOC

RNI No. 55787/93