BALLISTIC SYSTEM FOR ANTIASTEROID DEFENSE

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Introduction

In recent years the world community as well as various scientific teams have evinced a growing interest in the problem of preventing collisions of huge heavenly bodies (asteroids and comets) with Earth [1]. Such collisions, depending on the scale of event, may lead to either local catastrophic demolitions or a global holocaust. An encounter between Earth and another Tunguska–size meteorite may result in millions of casualties, if one takes into account the proliferation of hazardous industries nowadays. Collision with a kilometer–size asteroid constitutes a grave threat to the whole of mankind. Although the probability of an asteroid collision is fairly low, the conditional probability of any human being to be killed during such a catastrophe is on a par with the probability of dying in an aircraft accident or after nuclear power station burst. In other words, if we are not concerned with this pressing problem now, we may be overtaken by such an event. Hence, the threat of heavenly bodies to Planet Earth as well as the research of cost–effective countermeasures require appropriate consideration.

This paper reflects our attempt to build an economically feasible concept of an antiasteroid defense on the basis of a gasdynamic ballistic system capable of delivering thermonuclear projectiles to the desired zone of intercept with their subsequent detonation resulting from their high speed impacts on the asteroid's surface. The design of this type of a thermonuclear device precludes the need for fissionable materials. Command guidance from Earth is used to steer a projectile to its target. The projectile maneuvers by exploiting the kinetic energy stored in its rotational motion, i.e. the projectile spinning around its longitudinal axis. Collision of an asteroid with Earth is avoided by changing the incoming asteroid's trajectory, which change is forced by a series of thermonuclear detonations on its surface. In addition, these explosions disperse and partially evaporate the asteroid's body: its scattered fragments are substantially less hazardous should they hit Earth.

The enclosed figures illustrate various elements of the antiasteroid defense concept based on gasdynamic throwers. More detailed analysis of these issues is the subject of another paper which is now being prepared. The present paper is aimed at describing both the design of a gasdynamic ballistic system for the direct injection of projectiles into Outer Space as well as some issues concerning hypervelocity projectile transit through the dense atmospheric layers.

The ballistic system

The main part of the throwing system for directly launching projectiles into Outer Space is a ballistic bore which consists of a thick–wall tube pointing to the sky with a reloadable liner inserted into it. A powder gun with a rifled bore is mounted at the bottom for projectile injection. The bore is attached at its muzzle to a pontoon and hangs precisely vertically in a protective cylindrical canister which is also fixed to the pontoon and which prevents any disturbances of the subsurface ocean flows from reaching the ballistic bore. The suspension–type design of the thrower system helps to stabilize the ballistic bore after a shot thus ensuring a high linear accuracy. Deployment of the ballistic system in the ocean allows its relocation to practically any latitude which, coupled with the Earth rotation, provides the capability to hit any region of Outer Space within 1 million kilometers of the Earth. An ocean–based thrower system has some other advantages: (a) the recoil pulse dissipates effectively in the surrounding waters, (b) the excessive heat is easily transferred into the water, and (c) the requirements to reduce the acoustic impact on the environment are not as stringent in this case. Evacuation of air from the bore is done with ejection pumps fed by compressed air. To soften the impact of the projectile as it is injected into the dense atmosphere and to avoid its possible demolition, a smooth increase of pressure at the upper part of the ballistic bore near the muzzle is also provided by these ejection pumps.

Loading of the explosive charge is planned to be executed from the muzzle down the bore. First, pyropowder packs are loaded, and then the projectile is lowered. It is mounted in a sabot with a hexagonal driving band to steer it along the rifled gun barrel. This band makes it possible to load the powder gun from its muzzle. Then a distributed layer of explosive compound is inserted into the bore along its full length. This compound is a 5–mm thick plasticized PETN sheet. Strips of this sheet several centimeters wide are stitched in a regular pattern to paper cardboard sheets with not less than 1–mm gap (it should be noticed that gluing the strips with adhesives may substantially alter the parameters of the

explosive compound). Then each cardboard sheet is rolled into a tube and wooden rings are slipped on it along its full length. The external diameter of these rings is equal to the internal diameter of the ballistic bore with an allowance made for the plastic deformation of the bore's walls under the shock loads generated by each shot. The sections thus assembled with an explosive charge are loaded one by one down the ballistic bore. This type of the ballistic tube design does not require any precision metal–cutting operations. Gaps between the PETN strips prevent axial detonation of the distributed charge. The thickness of the wooden rings between the explosive layer and deformable liner in the ballistic bore is selected to dampen the shock wave to the point where it will not cause the mechanical destruction of the liner in which the rest of the shock wave energy is absorbed. The remnants of cardboard and wood, if any, are blown out of the ballistic bore with the powerful gasdynamic jet.

A preliminary boost of the sabot–equipped projectile to a speed of 1.5 km/s is carried out by a powder gun with a rifled bore. Both the projectile and its sabot gain translatory and rotational motion simultaneously. After the pre–boost the rapidly spinning projectile enters the evacuated ballistic bore with the explosives on its walls. The internal diameter of the bore is greater than the projectile caliber, hence the latter proceeds without any mechanical contact with the walls. Additional speed is transferred to the projectile by the successive detonation of the explosive strips as the projectile flies by. As the detonations begin, the sabot is discarded and starts to lag behind. Synchronous detonation is achieved because liquid, stored in the projectile, is sprayed out of the projectile side wall under the centrifugal force. Drops of the liquid hit the surface of explosive layers at a grazing angle which initiates detonation due to viscous friction and shock compression. At this time, gaseous products of detonation expand at a high speed towards the tube axis and collide on the cone aft of the projectile pushing it ahead, The translatory motion of the projectile without any mechanical contact with the ballistic bore walls is accomplished by gyrostabilization of its attitude and by the centering effect in the bore of the detonation products expanding towards the bore axis. Parameters of the full–scale ballistic system for antiasteroid defense are given in the figure.

Exploratory development of the high speed throwing technology is being conducted at the TsNIIMASH large–scale ballistic facility. By now 60 meters of the bore of the experimental 100–mm ballistic system have been manufactured. The final version of the experimental ballistic system will have the following parameters:

Ballistic bore length	150 m
Weight of the distributed explosive charge	up to 150 kg
Projectile caliber	85 mm
Projectile weight	1.5 kg
Projectile muzzle velocity	up to 12 km/s
Pre–boost muzzle velocity	up to 5 km/s
Projectile angular rate	up to 1600 rps

Upgrades of the experimental ballistic system are planned for the future to test an ocean–based version. In this case the length of the bore could be extended to 1 km. The pre–boost to 1.5 km/s will be executed with a powder pre–booster. The energetic capabilities of the ocean–based experimental ballistic system will allow it to launch into Outer Space projectiles weighing 3 to 5 kg.

Experiments to investigate detonation phenomena of the PETN explosive were carried out using a 1.5–gram plastic projectile of 12.7–mm caliber which was fired into a flat PETN specimen from a two–stage light–gas gun at velocities ranging from 1.2 km/s to 3 km/s and at impact angles of 30 and 90 degrees. The specimen was fixed with the same technology which is to be used in the design of the experimental ballistic system. It was revealed that initiation of detonation in the explosive layer occurred throughout the full velocity range when the impact angle equaled 30 . On the other hand, at the normal angle of impact, the explosive did not detonate even at 3 km/s. This can possibly be explained by the additional heating which the explosive surface experiences caused by the high–speed tangential flow of the projectile material along the specimen layer in the 30° case.

Ten explosive tests were carried out to assess the lifetime of the 100–mm bore of the experimental ballistic system. A 1.8–mm PETN layer was inserted into the tube section in compliance with the technique described above. Then the section was hermetically sealed from both sides with endocarps. The explosive detonation was initiated with an electrical detonator. Inner and outer diameters of the steel tube at various cross–sections were measured before and after the test series. It was established experimentally that after 10 tests the inner diameter of the tube incremented to not more than 0.2 mm. The

computed efficiency of the thrower using this approach matches the results published in Russian journals [2, 3].

Projectile hypervelocity atmospueric transit

In order to achieve the projectile's transit of the dense atmospheric layers at 13 km/s, the nose cone taper angle was selected to obtain a drag factor not greater than 10^{-2}. In this case the speed loss due to atmospheric drag is not more than 2 km/s assuming that this drag has a constant value. The sharp taper angle of the projectile can be sustained during the atmospheric transit because the projectile is fired vertically and the total duration of this transit lasts around one second. This permits the active heat protection design of the aerodynamic cone of the projectile to be accomplished with intensive coolant depletion. The ballistic cone itself is manufactured from a hard carbon — based material. Monocrystalline graphite, a modification with curled — up atomic layers which form a macrocylinder, was selected to build the cone. Ordinary monocrystalline graphite possesses flat atomic layers. The strength of monocrystalline graphite along the atomic layers is enormous (200,000 atm), and it withstands temperatures up to 2600°C. It is true that graphite atomic layers have weak interbonds, and it can be easily sliced like mica. However, should one manage to curl the atomic layers into a cylinder, this shortcoming will be removed. Because of graphite two–dimensional crystalline structure when the stress overcomes the rupture limit destruction proceeds according to the viscous mechanism, i. e. some additional work must be expended prior to rupture. In contrast to graphite, most of high–strength materials with three–dimensional crystalline structure demonstrate a brittle mechanism of destruction: the propagation of a crack is momentary and additional energy is not needed. The high mechanical strength of graphite together with its moderate density (2.26 g/cm^3) make it possible to spin a projectile made of this graphite so rapidly that the linear speed at its periphery can reach 3 km/s. At such angular rates cone ablation will proceed axisymmetrically, thus decreasing projectile deviation from the local vertical, and this substantial gyroscopic moment will stabilize its motion in the atmosphere. Another useful and important feature of monocrystalline graphite is its record heat conductivity along atomic layers (2,000 W/m·K), which is five times better than that of silver at a room temperature. The high heat conductivity provides protection for the graphite surface against overheating and sublimation in the high–speed air flow. However, above 600°C graphite readily interacts with atmospheric oxygen and the design of the heat protection means should be considered to block oxygen access to the graphite surface. Graphite oxidization can be overcome with the help of a layer of atomic lithium over the cone surface. The weak interlayer bonds of graphite permit substantial doping with lithium, up to one lithium atom per eight carbon atoms. The dopant atoms form bonds between the graphite's atomic layers without markedly altering graphite crystalline lattice due to the small atomic radius of lithium. Above 1500°C, as the heat wave proceeds in depth, the lithium interlayer bonds disintegrate violently liberating lithium atoms which will rise to the surface through the intact graphite crystalline lattice and yield intensive degassing. The atomic lithium flow provides active heat protection of the surface and it readily reacts with atmospheric oxygen thus impeding its access to carbon atoms on the surface. The high speed of heat propagation in graphite supports the needed level of lithium degassing per unit area. The thermal energy released during lithium oxydization is partially absorbed by endothermic disintegration of lithium interlayer bonds. This is the approach chosen to provide heat protection for the side surface of the projectile ballistic cone. The relatively short time of atmospheric ascent, the high heat and temperature conductivity of monocrystalline graphite, together with its ability to store large amounts of lithium make this a solid basis for the design.

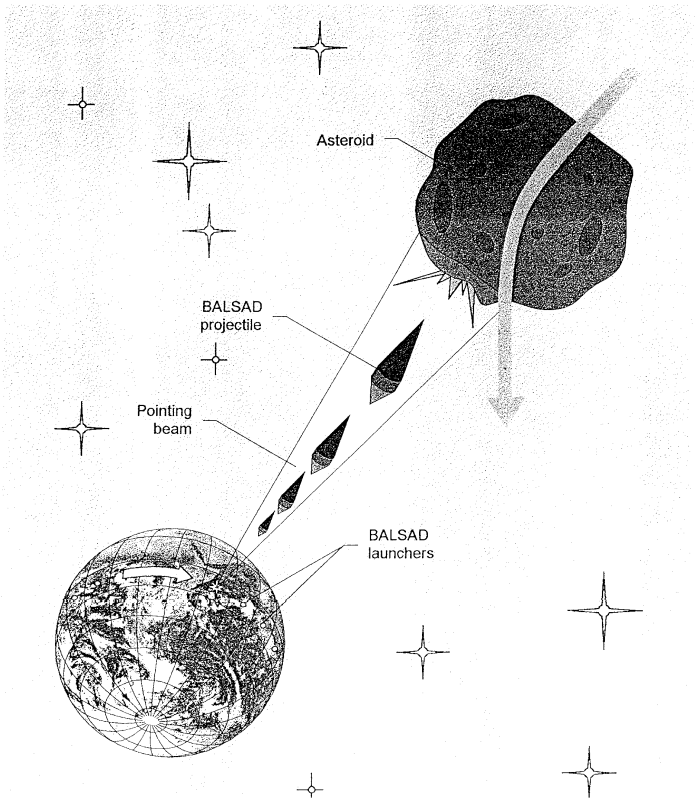
Unfortunately lithium doping is not enough to protect a tip of the cone. Indeed, if a 13 km/s projectile enters the lower atmosphere, which is known to have a density 1.23 kg/cu.m, then a powerful shock wave originates at its tip with a pressure behind the shock front of 2,000 atm and the temperature above 15,000K. At this temperature the major component of heat transferred to the projectile surface is in the near–UV. To protect the tip, a substantial gas flow is pumped through its outside. This gas must be inert with respect to graphite, have good absorption of near – UV radiation and be cool enough not to sublimate the graphite. The use of the gaseous products of some type of solid propellant combustion has been proposed. To implement this, an axial cavity is drilled in the projectile and filled with propellant powder. As the projectile enters the lower atmosphere, propellant combustion is initiated. The rate of protective gas depletion is an exponential function of the shock layer pressure. While the projectile rises, the pressure decreases and combustion slows down. The initial solid propellant mass is calculated, with these functions in mind, to provide heat protection along the whole path of the projectile in the atmosphere and amounts to about 10% of the total projectile mass.

At present research is being conducted to explore approaches to synthesize monocrystalline graphite. In particular, a technique of forced spatial orientation of its atomic layer planes has

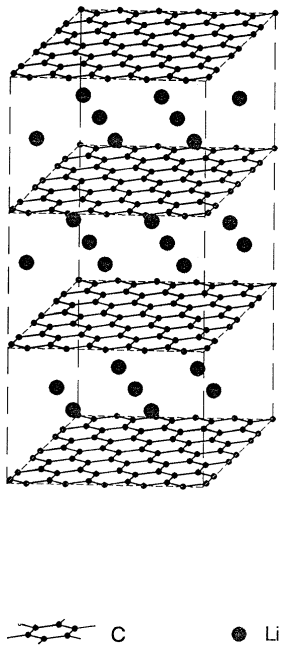
been found. This technique is applicable for layer orientation both in the process of graphite crystal growth and during high temperature annealing of the ready–made crystal. Proof–of–concept experiments have confirmed the feasibility of the key concept underlying the technique. In these experiments– the crystalline planes of the pyrolytic graphite polycrystal have been aligned to better than 0.1 angular degree under the proposed force factors, the initial polycrystal having a misalignment on the order of 20 degrees. Near–term plans include commissioning of a technological installation for graphite monocrystal synthesis which will be capable of putting into practice controlled growth of graphite crystals with a three–dimensional order to their structure. The major criterion for the crystal quality acceptance tests is the tensile strength in the direction parallel to its atomic plane.

Exploratory development of the active heat protection means of the projectile is planned to be carried out at the TsNIIMASH large–scale ballistic facility which after special upgrades will be capable of generating hypersonic flows of a cool air at Mach numbers between 40 to 50. Such flows are possible due to a tenfold radial compression of an air vortex which has an initial speed of rotation about 1000 m/s. The energetic capabilities of the facility makes it possible to obtain high–speed jets lasting for up to 100 ms during which time the air jet density decreases from its nominal value to zero, thus providing conditions for projectile atmospheric transit which simulate the real environment.

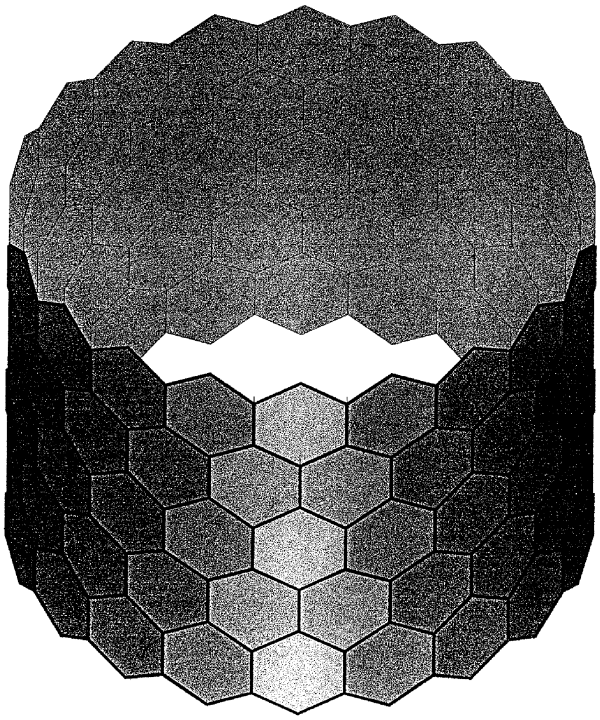
Ballistic System for Antiasteroid Defense



Structure of Graphite Doped by Lithium

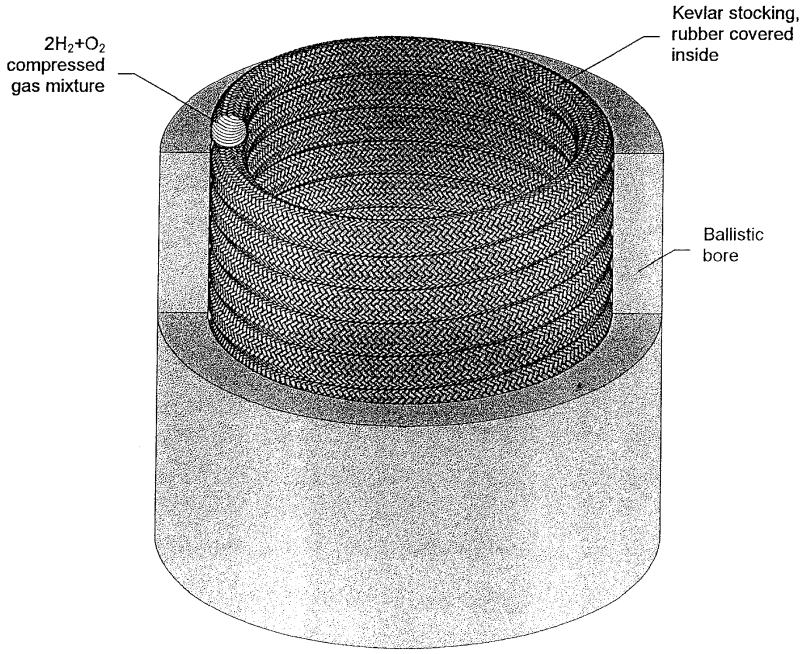


Cylinder-Shaped Atomic Layer of Graphite Monocrystal

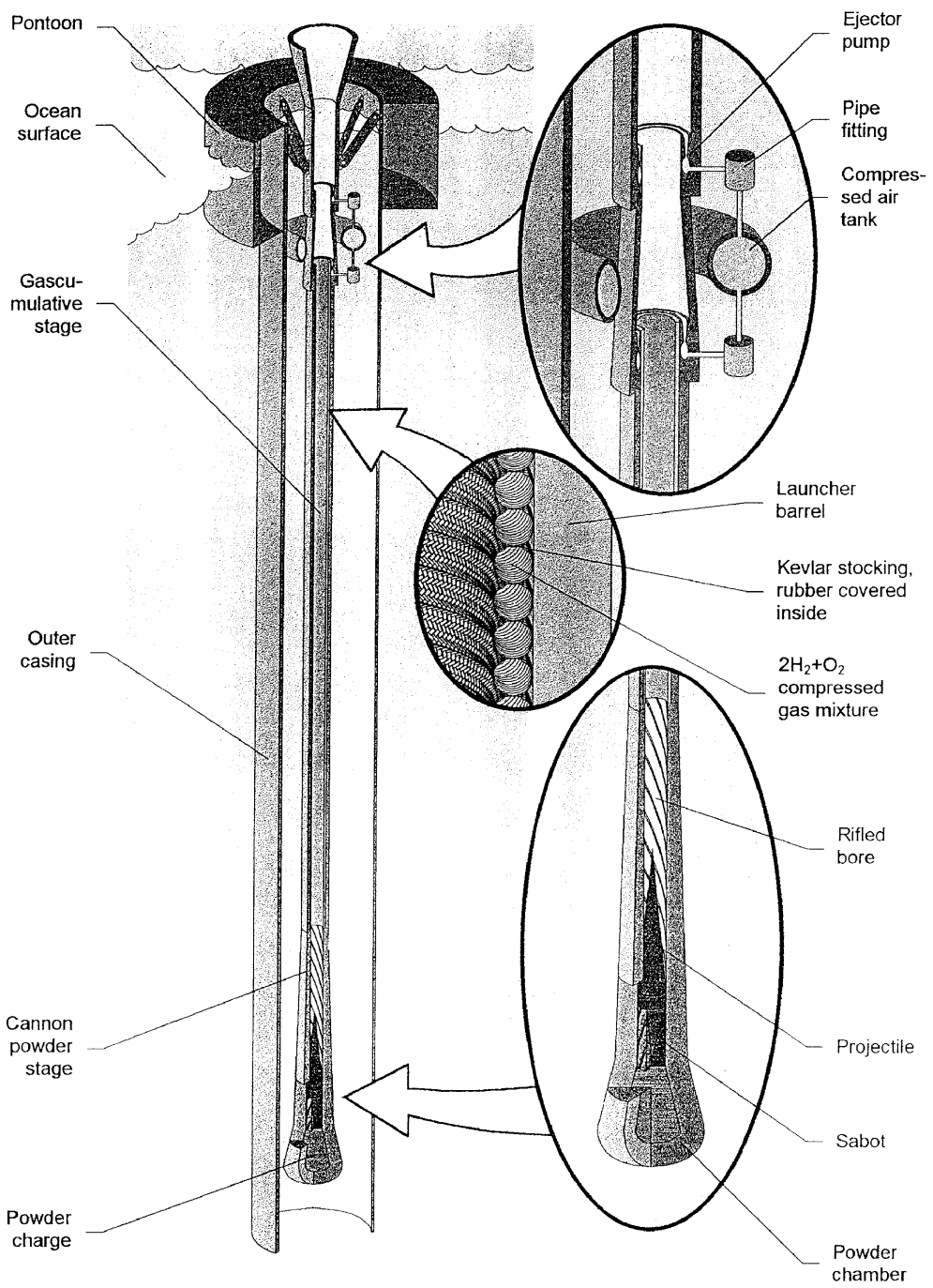


Utmost Rupture Stress along the Atomic Layer ..... up to 20 Gpa
Density..... .....about 2 260 kg/m^3

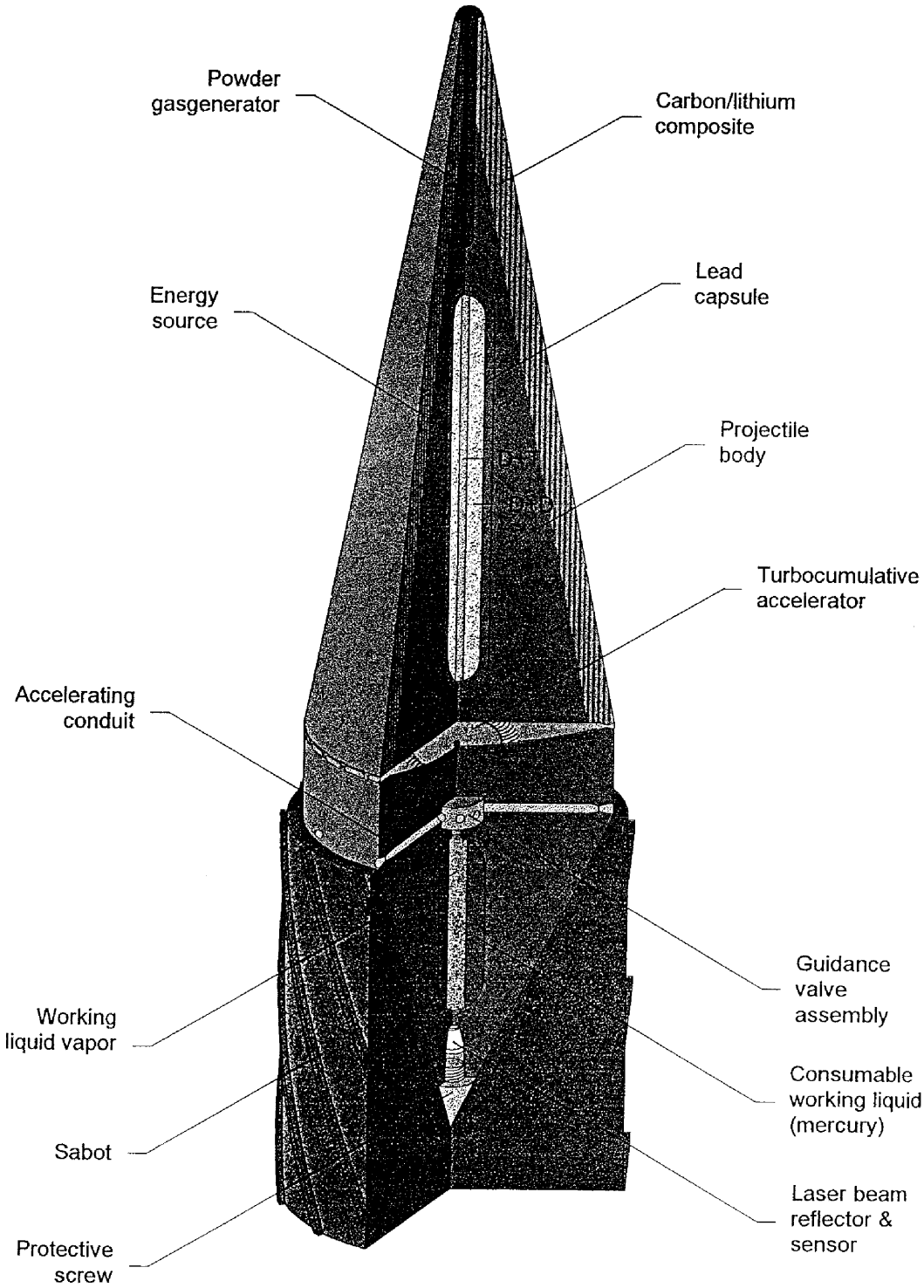
Desing of Ballistic



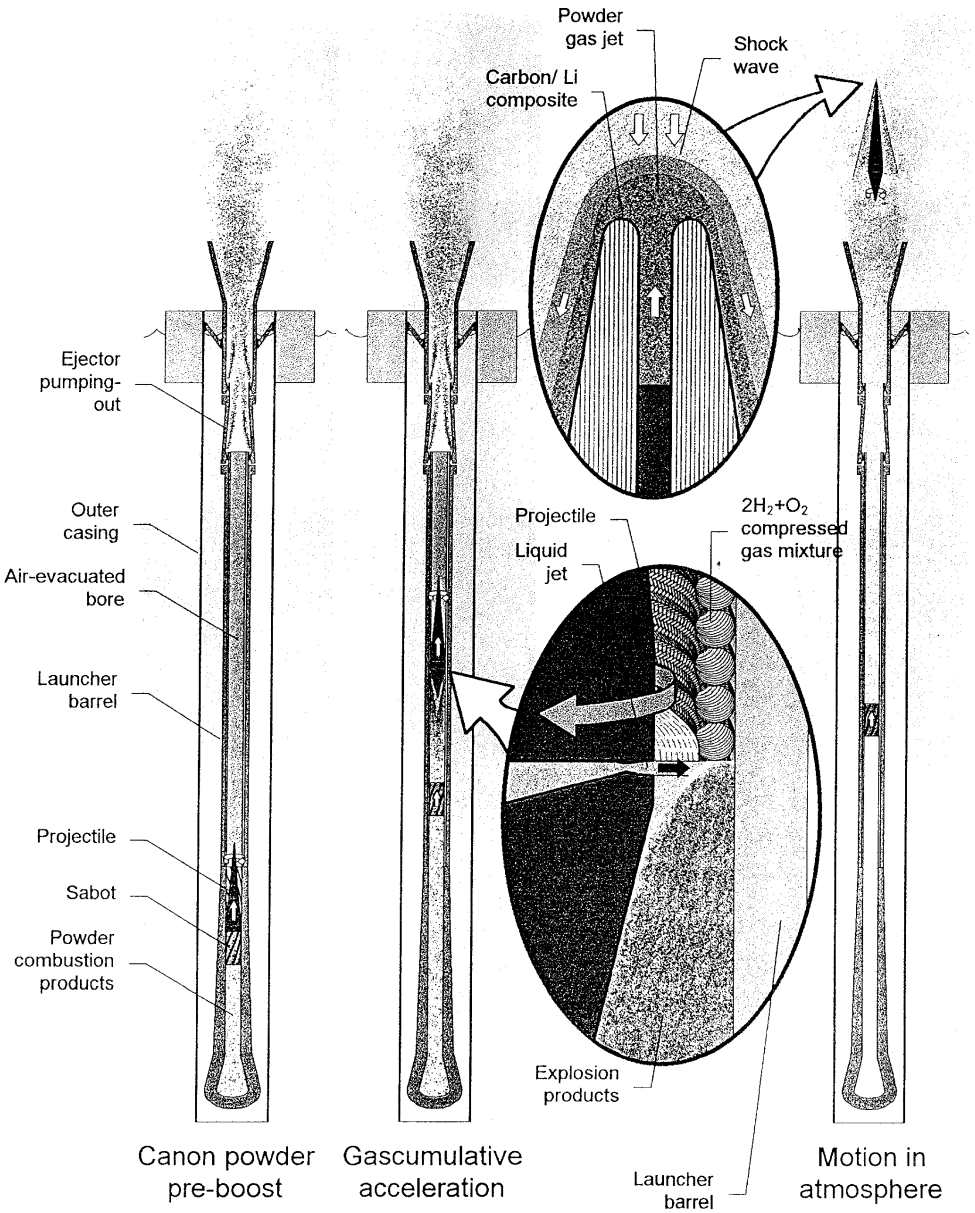
Ocean-based Ballistic Launcher



Projectile Design



Principles of the Ballistic Launcher



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