FTD-HT-67-462

FOREIGN TECHNOLOGY DIVISION

WARHEADS OF SURFACE-TO-AIR GUIDED MISSILES

by

S. Roglic

1917 1967
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EDITED TRANSLATION

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By: S. Roglic

English pages:31

SOURCE: Vazduhoplovni Glasnik, (Air Force Herald), No. 2, 1966, pp. 131-149.

Translated under: Contract AF33(657)-16410

YU/0009-66-000-002

TP7000972

PREPARED BY:

TRANSLATION DIVISION
FOREIGN TECHNOLOGY DIVISION
WP-AFB, OHIO.

Date 3 Aug 19 67

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ITIS INDEX CONTROL FORM

01 Acc Nr TP7000972	**68 Translation Nr** HT6700462	**65 X Ref Acc Nr** AP6027518	**76 Reel/Frame Nr** 1654 0750

97 Header Clas UNCL	**63 Clas** UNCL, 0	**64 Control Markings** 0	**94 Expansion**	**40 Ctry Info** YU

02 Ctry YU	**03 Ref** 0009	**04 Yr** 66	**05 Vol** 000	**06 Iss** 002	**07 B. Pg.** 0131	**45 E. Pg.** 0149	**10 Date** NONE

Transliterated Title
BOJNE GLAVE RAKETA

09 English Title
WARHEADS OF SURFACE-TO-AIR GUIDED MISSILES

43 Source
VAZDUHOPLOVNI GLASNIK (SERBO CROATION)

42 Author ROGLIC, S.	**98 Document Location**
16 Co-Author NONE	**47 Subject Codes** 16, 19
16 Co-Author NONE	**39 Topic Tags:** surface to air missile, warhead, cluster warhead, nuclear warhead
16 Co-Author NONE	
16 Co-Author NONE	

ABSTRACT: The warheads of surface-to-air missiles such as cluster warheads and nuclear warheads, and their destructive capabilities are described. A detailed description of components such as the igniter, detonator, and high-explosive charge as well as description of the electric, radio-command, radar, infra-red, magnetic, and optical target-seeking and charge-activating systems, the safety and self-destruction devices is given. A separate chapter deals with nuclear and thermonuclear warheads. Technical and tactical characteristics, especially concerning the destruction radius, zone, isotropic and anisotropic effect of the high explosive warhead, and the shockwave, heat, and radiation effect of the nuclear warhead, are given. Nuclear explosives in the 0.25 to 10 kiloton range are considered. Block diagrams of explosive and nuclear warheads, their components, system arrangements, and various patterns of explosives are presented. Some Soviet and Western types of surface-to-air missiles are named, among them the Soviet M-2, T-6, and T-8 SAMs. Orig. art. has: 10 figures. English translation: 31 pages.

FTD Form Feb 67 0-90

WARHEADS OF SURFACE-TO-AIR GUIDED MISSILES

Stevan Roglic

As we know, the modern surface-to-air missile does not in itself represent a military weapon, but it carries a warhead (WH)[1] to such a distance from its target from which it can be destroyed with certainty by detonation of its explosive section. In this connection let us assume that the missile is a center in which a warhead is placed and that around it there is formed a surface which determines the limit of its effective action. The circumference which is defined by this surface is called the *destruction zone* of the missile warhead. This zone corresponds to the diameter of the missile if it does not have a warhead, or exceeds this considerably, if it does have a warhead. We shall further assume that the destruction zone of the warhead travels together with the missile in its orbit (Figure 1). If the warhead comes into play at the moment when its destruction zone and the target are partially coinciding, the target will certainly be destroyed. If the missile has two or three warheads, it may be regarded as a group of missiles, whose warheads (each individually) form a zone of destruction.

There is a difference in the case of a missile which does not have a warhead. This missile, namely, can destroy the target with its own kinetic energy (simply like a bullet), or in an extreme case, with the explosion of the remaining liquid fuel and the oxidizer. On the other hand, a missile normally has no solid fuel or oxidizer, since this would lead to an increase in its weight and dimensions to a notably greater degree than when a warhead is supplied, which, nonetheless also has a noncomparable amount of destructive property.

Thus, it is obvious that if we consider the effective action of a missile which is not equipped with a warhead, we must completely disregard the explosion of the residual fuel and the oxidizer and consider only the result of the action of its

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[1] See page 29

Figure 1. Missile destruction zone.
(a) with WH; (b) without WH.

kinetic energy, which is, with respect to the requirements which arise in this regard, totally insufficient.

For this reason, surface-to-air missiles have been developed and equipped with powerful warheads, which represent the product of the most advanced science and technology in the field of armament. Depending on the type, these are usually composed of three elements: an igniter with an operating safety device, the detonating stage, and the explosive components. These provide a maximum destructive property and offensive quality for the missile, an explosion of the missile's warhead at the most appropriate moment, the safety of personnel, objects, and other material goods from an unintentional explosion or from the effect of the missile itself.

Ignition

It is of course essential that the target enter and remain in the zone of destruction of the missile's warhead, but this is not the only condition of the target's destruction. The indispensibility of the above-mentioned condition is obvious, because it is completely clear, if the target is not in this zone, the explosive action of the warhead cannot be effective under these given circumstances. Meanwhile, even if the target is to be found in this zone its destruction does not necessarily follow. The reason for this is that the destruction zone in reality does not exist until such time as the missile warhead does actually explode. Thus, if the warhead explodes too late or too soon, the target can pass through the destruction zone entirely undamaged.

The essence of this problem is completely solved by the application of an appropriate ignition system, which will determine the optimal time of detonation and, through the detonating stage, will cause the explosion of the missile warhead.

With respect to its principle of operation, we may devide these igniters into three types: percussion, time, proximity, and command. The *percussion* igniters are activated when they strike the target; *time* igniters, after the elapse of a particular period of time, starting from before or after the missile launch; *proximity*, as a result of energy which the target either radiates or reflects; and *command*, by means of a command received from a ground radio or radar station. In all these cases, the target must be in the destruction zone of the warhead, since otherwise the igniter will not be activated, and the missile will be destroyed by means of a self-destruct mechanism immediately upon the elapse of a given period of time, i.e., when it reaches an altitude which will guarantee the safety of friendly personnel.

In modern surface-air missiles the proximity igniter is most frequently applied, i.e., one which is activated by the effect of radiation or reflection of certain types of energy from the target, or as a result of various effects of the missile trajectory.

Targets which radiate a certain amount of energy can be aircraft, helicopters, various rockets and missiles, etc. During flight, these targets represent a source of radiation with resonant oscillations and of electromagnetic energy from infrared to ultraviolet rays. Simultaneously they represent a relatively good reflector of electromagnetic energy. The amount of energy at each point in atmospheric space around the target depends upon its position with respect to the target. If we know this relationship, the position of the target and the missile with respect to one another can be determined on the basis of the amount of the energy. In this fashion, the explosion of the warhead may be achieved at the optimal moment. This fact is the basis on which is founded the principal of operation of many types of proximity igniters.

With respect to its origins and the relative position of the sources of the energy whose proximity to the igniter serve to determine the moment of its activation, these may be divided into: *semi-passive,* which utilizes the energy which surrounds the target and is reflected from it (the source of this energy being in the atmosphere); *passive,* which utilizes the energy which the target is radiating (the source of the energy being the target itself); *semi-active,* which utilizes the energy which has been emitted from friendly ground radar or some other source and is reflected from the target (the source of the energy in this case being on the ground); and *active,* which utilizes the energy which, having previously been emitted from the igniter, is reflected from the target (the source of the energy being in the igniter itself).

With respect to the type of energy which is used in its operation, the proximity igniter is divided into the following types: *electrostatic,* which utilizes the energy of an electric field in its operation; *magnetic,* which utilizes the energy of a magnetic field in its operation; *radio,* which utilizes electromagnetic energy at the radiowave range in its operation; *optical,* which utilizes the electromagnetic energy of the infrared to ultraviolet range for its operation; and *acoustical,* which utilizes the energy of sound and other oscillations for its operation.

It should be noted that from among these types of proximity ingiters on surface-to-air missiles, the radio igniter is the most frequently applied.

Finally, we recognize as basic elements of proximity igniters the following, which for a given case include: power supply, transmitter, receiver, amplifier, and safety-operation device.

The *power supply* provides electric energy to its consumer, the proximity detonator. From the viewpoint of construction, this source can be derived in several ways: in the form of a galvanic cell, an electric generator, etc. The remaining supply of the electric system of the missile may also be utilized as igniter power supplies.

The *transmitter* has the task of converting the electric energy of the power source into another type of energy and emitting or radiating this energy in a given direction. The construction of such a device depends first of all on the type of igniter. Thus, for example, in the case of a radio igniter, the transmitter is a high-frequency oscillator with an antenna (a radio transmitter); in the case of an optical detonator, it is an illuminating element, i.e., one which lights or extinguishes a lamp with an object glass, etc. The transmitter is a basic part only of the active operation igniter, and is not to be found in the case of semi-passive, passive and semi-active igniters.

The *receiver* has the task of receiving the energy which came from or was reflected by the target and its transformation into electric voltage. The construction of this device also depends first of all on the type of igniter. In the case of a radio igniter, the device is a radio receiver; in the case of an optical igniter, a photo-cell with an optical system; in the case of an acoustical igniter, a microphone, etc. In a great number of proximity igniters the receiver is basically a set of so-called sensors and converter circuits. A sensor receives its influences directly from the target. When this happens, one of the parameters which characterizes its nature can be changed, e.g., the variation in resistance of the sensor in an electric current. The converter circuit converts a change in the nature of the sensor into electric voltage. At the output of the circuit we separate the voltage which represents the operating signal of the igniter whose appearance indicates that the target has entered into the sensitivity zone of the igniter. The amount of this operating signal depends upon the degree of change in the parameter of the sensor, or on the relative position of the target and igniter. At the moment when the position of the igniter, i.e., the missile with respect to the target, is optimal, the warhead explodes at the latest after 0.001 second.

The *amplifier* serves to amplify the electrical (operating) signal at the output of the receiver of the igniter. This amplication is indispensible, since the operating signal is usually weak and not adequate to switch on the thyratron of the operating element.

The *safety-operation device* has the task of connecting the igniter to the detonating stage and of transferring to the detonating stage the pulses which are necessary to activate the warhead. Basically, this provides for:

safety during the assembly, transportation, and general work with the detonator;

arming the detonator at a determined distance;

activating the missile warhead at the moment it is reached by the operating signal of the igniter;

self-destruction of the missile at a safe altitude in case the target is missed.

As can be seen from the name itself, this device consists of a safety and an operating section.

The *safety section* is a contact between the igniter and the detonating stage. It connects the detonating stage and the igniter only at a point when an explosion of the warhead would not represent a danger to friendly personnel, and when its activation is unavoidable. This means that it must be able to disconnect the contack when an explosion of the warhead is not desired. An effort is always made to establish a connection of the igniter with the detonating stage in such a way that the latest possible moment, i.e., the most appropriate moment, for the explosion of the warhead is achieved. In this fashion, the possibility of an unwanted explosion is notably diminished, especially in the case of nuclear warheads which might be exploded as a result of the reflection of objects in the neighborhood and obstacles which the enemy has created for the igniter. The safety section makes possible several degrees of security. Every degree of security involves a particular type of separation or connection of the contact between the igniter and the detonating stage of the warhead, so that activation is not achieved as long as the contacts of its degrees of security have not been broken.

The safety element can be mechanical, pyrotechnic, hydraulic, electric, etc.

A mechanical safety device is normally composed of inert parts which, as a reaction to inert forces created at the moment of acceleration or deceleration of the missile's flight, displace, and in this fashion engage a timing mechanism which, after a given period of time, connects the interrupted electrical system of the operating part of the warhead. The inert section can be also constructed in such a way that by its movement it will activate an electric or detonating cap in the detonating stage component.

An electric safety device is most frequently composed of several switches or power sources which are connected into the operation either by a mechanical or pyrotechnic system or by means of a radio command received from the ground. The composition and mode of operation of hydraulic and other safety mechanisms are similar.

Security when assembling, transporting, and working with the warhead thus requires that all units of the individual mechanisms be in a neutral position in which all activation is excluded. The safety devices which prevent the activation of these mechanisms are constructed in such a way that their resistance can support a certain amount of greater inertial forces, which can arise during the course of transportation and handling (such as impacts, shocks, and the like). Thus, security from this point of view is obtained during the assembly and transport of the igniter, the explosive parts, the detonating stages, and the like.

As is evident, there are the following basic security degrees which must be removed in order for the warhead to be activated:

when the missile is set up on the launching ramp, all elements of the warhead and the starting system must first be connected and fastened together (first degree of security);

after missile launch, the arming of the igniter forms the second degree of security, which protects friendly territory from an unintentional explosion of the warhead;

in the immediate vicinity of the target, the third and last degree of security

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is removed by means of a radio command from the ground. This degree had prevented the warhead from being prematurely activated by means of radiation from local objects, targets in the atmosphere which in a given situation are of no interest, or from radio transmitters and other jamming which the enemy may have created.

The *operating section,* after receiving a radio signal from the igniter, has the task of activating the detonating cap of the detonating stage. In most cases, this element consists of a thyratron, which causes a circuit to be set up composed of a combustion capacitor and an electrically activated cap. The self-destruct mechanism is also found in the operating section.

After the igniter has been armed, and the last degree of security has been broken, the capacitor is feed from a voltage which is sufficient to activate the electric cap of the operating section. At the same time, its discharge system is separated, and its connection is effected by the thyratron on whose own system a negative voltage of the power source is operating. When the thyratron is connected, and the circuit set up, the operating signal is given by the igniter. This can be accomplished only when the operating signal of the igniter is at a given intensity, which is obtained at the moment when the target enters the destruction zone of the warhead. After the circuit has been set up, the capacitor is emptied by the thyratron and the fuse of the electric cap. Now the fuse glows and burns up the charge of the electric cap, which transfers its flash to the detonating cap, and the latter to the detonating stage and further to the explosive charge which the warhead activates. As can be seen, the electric cap of the operating section is activated electrically by the charge of the capacitor, and not by the signal of the igniter. This also follows from construction requirements, since if the operating signals of the igniter were directly to burn the electric cap, the amplifier of the igniter would have to be much more powerful, heavier, and larger.

Detonating Stage

The signal which the igniter receives from the target, the directional system, and the time mechanism are too weak to be able to cause the detonation of the insufficiently sensitive high-explosive charge of the warhead. This signal can be amplified by means of an electric device, explosive materials, or a combination of these. Except for some percussion igniters, which can cause an explosion as a reaction to mechanical forces and inertial forces, nearly all the other igniters produce electric signals for this purpose. The detonating stage receives these signals in the form of electric pulses, which it reinforces with its own detonations, and thereafter transfers them to the explosive charge of the warhead in order to achieve the latter's detonation. The detonating stage may be of a variety of constructions. Most frequently it is composed of a detonating cap, a detonator, a detonating explosive charge, and a sleeve. It can take the form of a cap, a tube, or a cylinder; and it is normally located in the path of the explosive charge of the warhead, if it is single; if it is two-sided, on the upper side.

The *detonating cap* has previously been filled by the primary explosive, which was ignited by the flame of the cap of the igniter. In order to decrease the amount of very sensitive and dangerous initial explosive, a combined detonating cap has been developed, composed of both the initial and the high-explosive elements.

The *detonator* serves to amplify the pulse of the detonating cap, and to produce the energy which is indispensible for causing the explosion of the warhead. It represents essentially a large amount of explosive of the same sensitivity as that of the charge of the explosive section of the warhead. The explosive part which is closest to the detonating cap is of a lesser density, so that its detonating wave can be more easily and reliably received, reinforced, and transferred to the explosive section of the warhead.

The *detonator sleeve* which unites all elements of the detonator in one whole is made of a steel, copper, or aluminum sheet. The thickness of its walls amounts to from 0.5 to about 3 mm; and it must, on the one hand, protect the explosive charge of the detonator from mechanical concussions, inertial forces which occur at the point of missile launch, and other influences which might activate it, and on the other hand allow for an easy transfer of the detonation to the charge of the explosive section of the warhead.

Explosive Section

From the foregoing we have come to the conclusion that the zone of destruction formed by the kinetic energy of the missile is so small that it would be inappropriate and indeed quite foolish to aim at fast-moving and maneuverable targets in the atmosphere with a missile without a warhead. We have also seen that a warhead notably increases the destructive capacity of the missile. In large measure, it is the explosive section of the warhead which basically represents the missiles payload and serves to destroy the target in the air not only by a direct hit but, and much more likely, by its explosive effect on its immediate enviorment. In this fashion, errors which unavoidably arise in the process of achieving a *rendezvous* between the missile and the target can be completely avoided by means of a guidance (or homing) system.

The explosive section is composed of two basic elements: the explosive charge and the housing, or sleeve.

The *explosive charge* is a solid mixture which, under the influence of a common pulse, suddenly separates and undergoes a chemical change, while developing a high heat and a large quantity of gas. These can be high explosives[2] (TNT, PETN, hexogen, hexolene, and others), nuclear (uranium and plutonium), and indeed the thermonuclear (isotopes of hydrogen, dueterium and tritium, or their combination with lithium) explosives.

The *housing* is made of hard cast, forged, or pressed steel. Its geometric shape, configuration, width and depth depend on usual aerodynamic conceptions, the tactical application, and other properties of a missile. Its basic task is to unite all elements in one container and the render impossible a premature or anarchic dispersal of the explosive charge, and for this reason it is useful in a high degree in the explosion process. Thus, with many typical explosive sections of the warheads of surface-to-air missiles, the housing is a unit of material from which, dur-

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[2] See page 29

ing the explosion process, a certain number of fragments of a desired shape and weight are formed.

Since the explosive section represents the principal and, one might say, the only actually destructive element of the warhead, the latter has taken its name from this section. Thus, for example, if the explosive section has a fragmentary (or fission or nuclear) action, it is known as a fragmentary (fission, nuclear, etc.) missile warhead.

The explosive parts, detonating stages, and igniters of the warhead are kept separated in special structures at a safe distance from one another and are equipped from the engineering point of view so that they will not constitute a danger either in the case of a premature explosion or as a result of enemy air action.

They are placed at locations in the missile and connected together and with other elements, then tested with a view to the general application of the missile for military purposes. The final assembly and testing of the warhead in most cases does not take much time; however, it is a delicate and critical process, involving a conscientious and scientific attention to the requirements of the technical system.

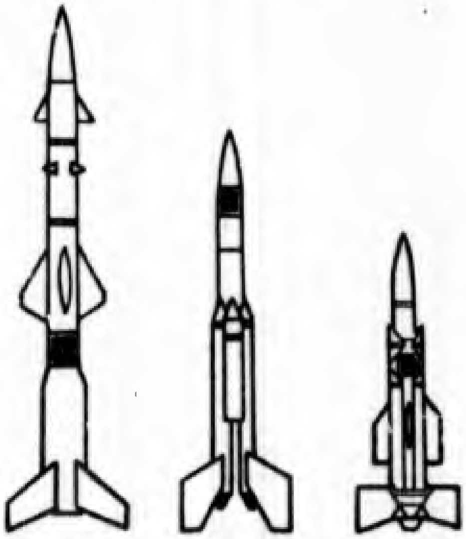

Figure 2. Principal systems for installing the warhead on a missile. (a) rear location; (b) forward location; (c) center location.

Depending on the design and other characteristics of the missile, the warhead may be placed in the forward, middle, or rear section of the missile. Furthermore, one surface-to-air missile can be equipped with 1, 2, or 3 completely separate warheads arranged in its container (Figure 2).

Depending on the type and general characteristics of the warhead, the process whereby it is activated and exploded is basically developed in the following fashion (Figure 3).

When the target reaches the missile launching zone, launching occurs and the missile is guided toward the target. When it has reached a certain distance from the target, a radio command is sent from a ground radar station to the safety unit of the igniter. Upon receipt of this command, power is switched on for the receiving and transmitting apparatus and for the amplifier. At the same time the last degree of security of the igniter is also removed. After its tubes are warmed up, which occurs practically immediately, the amplifier's transmitter begins to radiate uninterruptedly through the transmitting antenna electromagnetic energy in the form of a funnel in the direction of the missiles flight, which coincides completely with the diagram of the dispersion pattern of the warhead. The target having been reached, a part of the electromagnetic energy is reflected from the target and reaches the receiving apparatus of the igniter *via* the receiving antenna. In the receiving apparatus this energy is transformed into an electric signal, which thereafter passes into the amplifier in which its amplification to the desired amount of voltage is accomplished. This gain, now in the form of an operating signal, proceeds to the operating section in which it cuts the thyratron relay and thereby creates the ignition circuit. The capacitor is discharged and the electric cap is ignited, which transmits its flame to the detonating cap. The detonating cap is detonated and *via* the detonator causes detonation of the explosive section which, depending on the type of warhead, will destroy the target in the appropriate fashion. This occurs at the moment when the target reaches the destruction zone of the warhead. If the missile flies by the target at a distance which is greater than the activation radius of the igniter (i.e., the target was not in the destruction zone of this warhead) after a certain time when the missile has achieved a safe altitude, the selfdestruct mechanism causes it to explode.

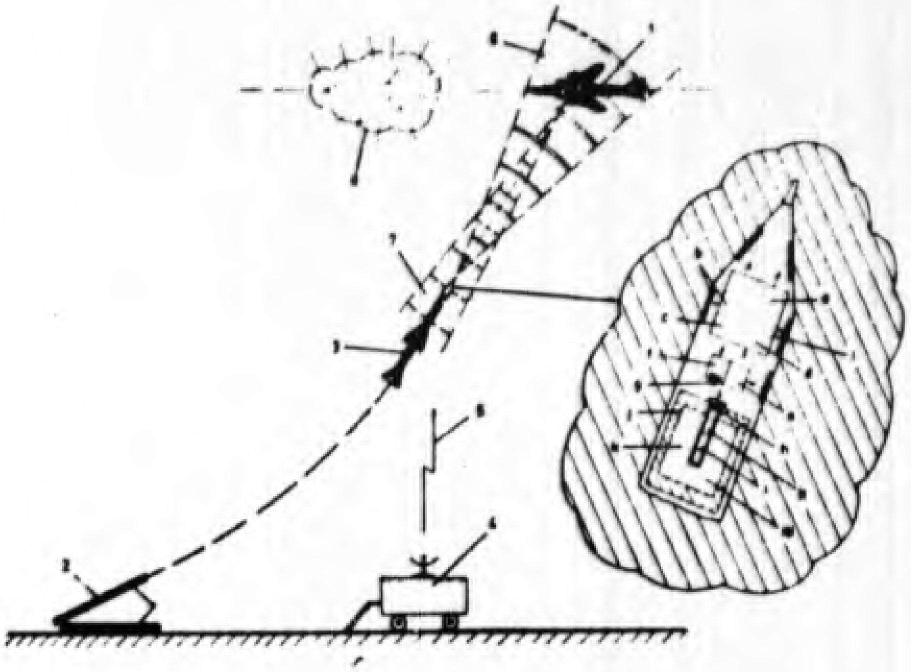

Figure 3. Schematic diagram of the activation of a warhead and the elements of its apparatus. 1. target; 2. launching ramp; 3. missile; 4. ground radar station; 5. radio command to the safety section; 6. beam of electromagnetic energy radiated by the igniter; 7. beam of electromagnecic energy reflected from the target; 8. explosion of the warhead and destruction of the target. Diagram of the warhead. I. Igniter: (a) transmitter; (b) receiver; (c) amplifier; (d) electric power source; (e) safety section; (f) operating section; (g) electro-inert capsule*. II. Detonating stage: (h) detonating cap; (i) detonator. III. Explosive section: (j) container; (k) explosive charge).

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*N. B. This probably a misprint for "electric cap".

Fragmentation and Nuclear Warheads

Surface-to-air missile warheads can be fragmentation and explosive (classical, nuclear, or thermal nuclear), cumulative, incendiary, or chemical. However, the warheads most widely used on these missiles are the fragmentation and nuclear warheads, and with these we shall briefly acquaint ourselves.

The fragmentation warhead. If there is a direct hit on a target in the air, it is not necessary to have a large weight of fragments in order to destroy the target. Thus, for example, the total weight of fragments required for the destruction of a modern fighter or reconnaissance aircraft is only about 100 grams; and to destroy a modern bomber, only 600 grams are required. However, as we have seen earlier, it is very difficult to achieve a direct hit on the target, since the existing guidance systems do not always function under all meteorological, tactical, and other conditions with the precision which is required. For this reason the fragmentation warhead is most frequently applied on surface-to-air missiles, since it can destroy a target in the air not only with a direct hit, but also by exploding 40-80, or even more meters away. It is understood that the weight of such a warhead must considerably exceed the weights which were earlier considered as essential for the destruction of various targets by a direct hit. The weight of the fragmentation warhead will amount to 20-250 kg, or about 5-10% of the total weight of the missile. In order to determine the weight of the warhead, on which its effective radius of action depends, we will first examine the functional accuracy of the guidance system with which the missile is provided: the more accurately the system guides the missile to the target, the more effective is the radius of action, and the weight of the warhead may be reduced, and vice-versa. The number of fragments of a desired shape, weight, and disperson pattern also depends on the weight and structure of the warhead, as do their destructive properties.

In modern surface-to-air missiles, two types of fragmentation warheads are applied: those with prepared fragments which are placed in the container of the explosive section of the warhead, and those whose fragments are formed from the container of the explosive section at the time of its explosion. It should be pointed out that the second type of warhead is much more widely used.

When a conventional fragmentation warhead explodes, many fragments of different weights are formed, of which only a part can be used to destroy the target. It has been determined that about 30-40% of the total weight of the container of the explosive section of a fragmentation warhead is consumed in the formation of small particles which serve no purpose, i.e., they do not possess the kinetic energy which is necessary for the destruction of a target in the air. It is clear that this leads to a perceptible decrease in the overall military potential of the missile. This shortcoming can in large measure be averted by forcing a disintegration of the container of the explosive section of the warhead into the required number of fragments of the weight desired. In Figure 5 the explosive section of a fragmentation warhead is shown which, with respect to the general aerodynamic configuration of a missile, *inter alia*, may also have a second shape. A system of special scorings has been made on its surfaces which will act as stress concentrators and indicate where the fragmentation of the explosive section of the warhead is to take place. However, experimental explosions have shown that the type of scoring shown in Figure 5 does not guarantee that a container will be fragmented along these lines, since the splitting along the transverse scoring does not in fact occur.

Fragmentation can be stabilized if the scoring pattern is based on a given angle with respect to the axis of the cylinder, as is shown in Figure 6. The angle of inclination of the scoring, which can also be applied to the interior side of the container of the explosive section, depends on certain design parameters and the characteristics of the material from which it is made.

If the explosive section of a fragmentation warhead has the form of a true cylinder (Figures 4, 5 and 6), which is most often the case, it is best to construct it in the form of a telescope composed of two tubes which are firmly attached to each other (Figure 7). On the internal surface of the exterior tube and external surface of the interior tube we apply a scoring pattern in the shape of a rhombus, which

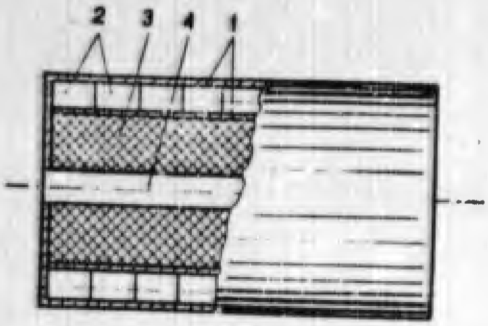

Figure 4. Schematic diagram of the explosive portion of a fragmentation warhead with prepared fragments. 1. container; 2. prepared fragments; 3. explosive charge; 4. space for inserting detonating stage.

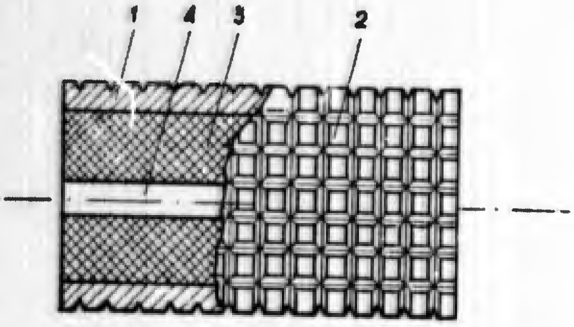

Figure 5. Schematic diagram of the explosive section of a fragmentation warhead with a scoring system in the shape of a rhombus. 1. container; 2. scoring system; 3. explosive charge; 4. space for inserting detonating stage.

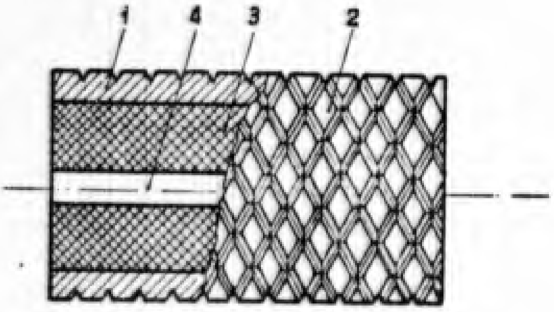

Figure 6. Schematic diagram of the explosive section of a fragmentation warhead with a scoring system in the shape of a rhombus. 1. container; 2. scoring system; 3. explosive charge; 4. space for inserting detonating stage.

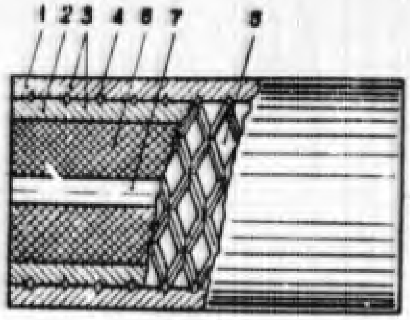

Figure 7. Schematic diagram of the explosive section of a warhead with telescopic container assembly. 1. exterior tube; 2. interior tube; 3. container; 4. scoring pattern of the exterior tube; 5. scoring pattern of the interior tube; 6. explosive charge; 7. space for insertion of the detonating stage.

may, but need not necessarily coincide for the two tubes. In this fashion, the container of the explosive section of the warhead will be much more easily, quickly and reliably split up into the calculated number of fragments, since now, as distinct from the earlier cases, splitting will occur simultaneously in two places; in the body of the exterior and the body of the interior tubes which, considered jointly, form the container of the warhead section.

The fragmentation of the explosive section's container into the desired number and weight of fragments depends on the diameter and the weight of the warhead, the weight of fragments depends on the diameter and the weight of the warhead, the weight and nature of the explosive charge, the mechanical characteristics of the metal from which the container is made and its structure, the angle of *rendezvous* of the missile and target, ignition type and characteristic, etc.

The advantage of the fragmentation warhead over other classical types consists in the fact that by applying various construction methods we may change the size, shape, direction of spread, and the velocity of the fragments from sonic to supersonic as well increase considerably the parameters of the warhead's zone of destruction. The explosive energy released by such warheads is approximately proportional to the distance or the squared distance from the point of explosion. By analogy, the effect action of the warhead's explosive part changes in proportion to the weight of its explosive charge or the square root of the weight of its explosive charge. Thus, it is possible to considerably increase the range of the action by restricting the weight of the warhead's explosive section. The effective range of action of a fragmentation warhead is usually greater than that of an explosive warhead of the same weight. Moreover, the last action of a fragmentation warhead, which does not have essential significance and is normally taken into consideration when evaluating its military qualities, can not be neglected in this connection, since for this purpose it consumes considerably more of its energy than does the fragmentation action of an explosive warhead.

The disadvantage of fragmentation warheads consists in the fact that the damage they can inflict on the target is not as great as the damage inflicted by an explosive warhead, especially at the maximum distance from its explosion.

The particles which are formed by the explosion of the warhead can damage the target in several ways. If their density is sufficient, individual structural members of the target can be broken off or damaged so greatly that the aerodynamic load and shock wave will stop the forward movement of the aircraft. Fragments may penetrate the target and cause fuel to ignite or ammunition to explode, damage the steering mechanism, put the engine out of operation, wound or kill the aircraft's crew, destroy or by other damage bring about the destruction of missile warheads of different types during the time of their flight toward their own targets, etc.

An examination of the fragmentation warhead would not be complete if we did not become acquainted with the reciprocal connections between the dispersal and the decrease of explosive energy of the warhead, and how practical advantage may be taken of the same.

Let us assume that the energy of the explosion spreads out from its explosive point (the center of the warhead) in a straight line and equally in all directions. Thus, the ratio of the speed of movement of the shock wave to its distance from the center remains constant at any point in space. Under these circumstances, the front of the shock wave will have at any moment the form of a spear. The action of the warhead, the energy of whose explosion is propagated in this fashion, is called *isotropic*. Such a warhead has the same effective action in all directions at the same distance from the center of the explosion.

Now let us see some of the advantages this has over a fragmentation warhead whose energy is entirely consumed in creating the kinetic energy of a large number of particles.

When an isotropic-action fragmentation warhead is exploded, a spherical envelope is formed of the same thickness as the warhead, which is composed of a large number (3-4 thousand) of fragments weighing from 8 to 15 g, uniformly distributed along its entire surface. Since the surface of the sphere grows proportionally to the square of its radius, the density of the fragments changes in inverse proportion to the square of their distance from the center of the explosion. If we assume that all remaining parameters of the explosive charge, except for its weight, are constants, we can say that the maximum effective range of the explosive part of this warhead is proportional to the square root of the weight of its explosive charge.

There remains a second type of fragmentation warhead, the particles of which, after explosion, disperse only in one direction in funnel form. The action of this type of warhead is called *anisotropic*. In this case the density of the particles changes in inverse proportion to their radius from the center of the explosion. This means, for example, that at a distance of 30 meters the density of the fragments will be three times less than at a distance of 10 meters from the center of the explosion.

We have described the isotropic-action fragmentation warhead only in order to better comprehend and more clearly point out the advantages of an anisotropic fragmentation warhead, which is of particular interest to us. We have seen that the isotropic fragmentation warhead has a nondirectional action, which can destroy a target with a given efficacy which is uniform in all directions. Let us now consider a warhead which after exploding can concentrate all its energy in only one or a number of directions. It is obvious that the degree of destructive capacity of these warheads will be different in different directions at the same distance. In other words, if the weight is the same, and anisotropic warhead is incomparably more effective than an isotropic in one or several directions, and less effective than the latter in all other directions. This means that if the flight trajectory of the missile is adjusted so that at the moment the warhead explodes the target is in a cluster of fragments, an anisotropic warhead will insure an incomparably greater destructive capacity than an isotropic warhead of the same weight. On the other hand, in using the anisotropic or directional warhead, a proximity igniter is required, which will determine the precise location of the target with respect to the missile. Then, allowance must also be made for the relative velocity of the target with respect to the missile (due to lack of space we cannot discuss this further) and for the characteristics of the warhead's action. Activation must be effected at the moment when the target reaches the cluster of dispersing fragments.

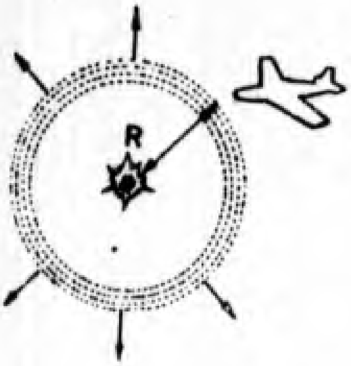

Figure 8. Characteristics of an isotropic fragmentation warhead.

In order to even better describe the advantages of an anisotropic fragmentation warhead over an isotropic warhead whose explosive section is of the same weight, we shall introduce the concept of *action amplification*. In this connection we may recall that the front of the shock wave or the dispersal of the particles of an isotropic fragmentation warhead takes the form of a spear whose center is identical with the center of the explosion. This uniform spreading of the explosion on all sides can be changed into a directional spreading in which the maximum effective range of action will be achieved only in one given direction (Figure 9). The ratio between the maximum velocity parameter of the explosion of an anisotropic fragmentation warhead (i.e., the pressure and the front of the shock wave or the density of the particles) and the maximum velocity parameter of the explosion of an isotropic warhead is called the *action amplification*.

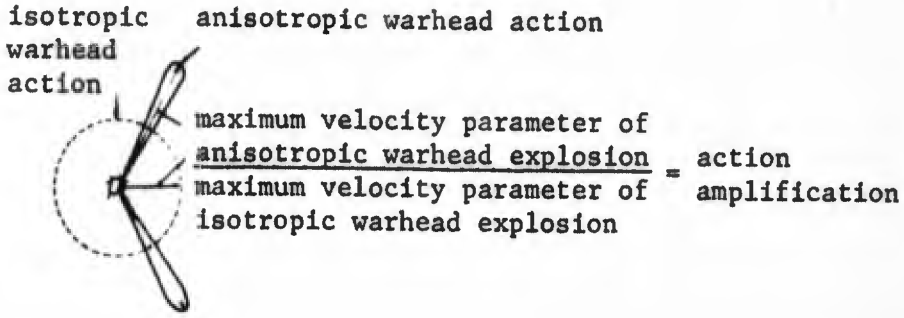

Figure 9. Characteristics of an anisotropic fragmentation warhead.

Action amplification offers an extraordinary qualitative characteristic, by virtue of which the anisotropic warhead has an undoubted advantage over all other types of classic warheads. They are what cause the surface-to-air missile to become indeed the most effective military weapon in modern antiaircraft defense. The probability of destroying a given maneuvering target with one of these missiles amounts to about 65-70%. This means that in order to destroy the target only two missiles or even one missile may be launched if it is equipped with a powerful fragmentation warhead with anisotropic action.

The Nuclear Warhead. As we know, the material required for a nuclear explosion is basically a fission (uranium-235 and plutonium-239) and it has a certain critical mass[3]. Explosion cannot be achieved in the case of masses which are less than the critical amount. For this reason, the explosive section of a nuclear warhead is constructed so that it consists of two separate parts, often of hemispherical shape, which each separately has a mass less than the critical amount and the total mass is equal to or more than the critical amount. A conventional explosive is used to make the momentary connection of these two hemispheres in a vacuum, and once the critical mass has been achieved, to bring about the explosion of the nuclear warhead. The ordinary explosive is activated by the igniter through the detonating stage.

Neutron reflectors make up the firm housing of the nuclear explosive charge which plays the role of a neutron which, having escaped from the fission material, is reflected and returns through the nuclear reaction zone. It is owing to the modern neutron reflectors which are made of graphite or beryllium oxide that the use of explosive charges in nuclear missile warheads has been increased.

The steel housing or sleeve of the explosive charge prevents a premature dispersal of the nuclear explosive and in this way increases the possibility of its wider utilization.

Action of nuclear surface-to-air missile warheads is also based on the familiar phenomenon of an uncontrolled chain reaction splitting of an atomic nucleus into its chemical elements. When the nucleus is split, a number of neutron particles of the atom are released which, for their part, cause further atomic nuclei to split, etc. During the process of atomic chain reaction splitting, which is practically instantaneous (less than a millionth of a second) a tremendous amount of energy is released, which exceeds a million times the energy created in the explosion of classical warheads. This extraordinarily rapid release of a huge amount of energy, caused by the reaction which is taking place in the explosive charge, is what we call the explosion of a nuclear missile warhead. In such an explosion the

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[3] See page 30

released energy acts in the form of a powerful shock wave (shock action), heat radiation (incendiary action), and the action of nuclear or radioactive radiation, which does not exist in the case of a classical warhead. In briefest form, these are the basic characteristics and effects of nuclear warhead action, which are indeed very dangerous for aircraft and other aerial targets.

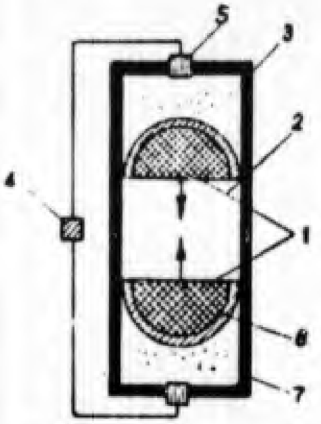

Figure 10. Schematic diagram of a nuclear warhead. 1. nuclear explosive section; 2. vacuum chamber; 3. conventional explosive; 4. igniter; 5. detonating stage; 6. neutron reflectors; 7. casing.

If we consider the total amount of energy released in the explosion of a nuclear warhead, about 50% of this is manifested in shock action, 35% in incendiary action, and 15% in nuclear radiation action. The effect of each of these actions on an aerial target depends upon a number of factors, of which the most important is the power and altitude of the warhead's explosion.

Shock action lasts several more seconds than in the case of the explosive effect of a conventional warhead, whose shock action amounts only to a few thousandths of a second. This is caused by the gaseous combustion in the fireball (to more than ten million degrees of heat), the very high pressure at the center of the explosion (over ten billion atmospheres), and the tremendous velocity of the particles (molecules) of the surrounding atmospheres. The shock wave at first moves at a supersonic velocity which about 500 meters from the center of the explosion drops to the velocity of sound, and after 3 kilometers to about 100 m/h.

The shock action radiates in all directions and is the principal destructive force of the missile warhead, especially in the case of explosions below 30 km in altitude. Its effect may be approximated by ascertaining the amount of pressure which it creates (in kg) on a square centimeter of an aerial target. In analogous experiments in the Nevada desert (USA), it was ascertained that at a pressure of 0.17 kg/cm^2 the exterior surface of an aircraft is broken, at a pressure of 0.25 kg/cm^2 the body of the aircraft incurs damage, and at a pressure of 0.42 kg/cm^2 the aircraft is completely destroyed. On the basis of this, it was ascertained that in the case of the explosion of a nuclear warhead of 1 kiloton all aircraft were completely destroyed which were in a radius of 600 meters from the center of the explosion, and in the case of warheads of 10 kilotons, in the radius of about 1300 m.

However, at altitudes above 30 km, the effect of the shock wave action sharply decreases due to the low density of the atmosphere. Thus, the energy which is changed into a shock wave in a denser atmosphere now remains in the form of heat energy, so that the incendiary action is increased from 35% to about 85% of the total energy released by a nuclear explosion.

The *incendiary action* appears as a result of the heat radiation of the fireball and lasts for several seconds. It spreads out in a straight line at the velocity of light. The waves are about 56% infrared, 31% visible, and 13% ultraviolet. The ultraviolet radiation is only momentarily emitted. The greatest amount emitted is the infrared radiation which for this reason has the greatest effect. Because of its short duration, incendiary action does not penetrate the material, but causes surface heating, melting, carbonizing, and combustion of the aircraft and other aerial targets. The crew of the aircraft can undergo severe burns. Thus, for example, a nuclear missile warhead of 1.5 KT can, upon exploding, inflict third-degree burns at a distance of 640 m, and a 10 KT warhead at a distance of 6,000 m.

The incendiary action of the warhead has a greater radius in comparison with the shock and radioactive action. As was earlier pointed out, the strength and effect of incendiary action sharply increases with altitude.

Nuclear radiation action is a specific characteristic of nuclear energy. It occurs during the course of and long after the explosion, and therefore for practical reasons it is separated into initial (primary) and subsequent (secondary) radiation.

Initial nuclear radiation consists of neutron and gamma rays and lasts usually from 10 to 15 seconds. It spreads in a straight line at the velocity of light.

Subsequent nuclear radiation consists of gamma, alpha and beta rays, and begins one minute after the explosion, arising from products of the nuclear explosive element which did not undergo fission, and from artificial radioactivity caused by the action of a neutron during the initial radiation, the so-called induced contamination or radioactivity. This can last from several seconds to several hours.

As a result of the initial and subsequent nuclear radiation, the crew of the aircraft and a-1 on board may exhibit radiation injuries or radiation diseases of a general type, depending on the dose and kind of radiation received. Moreover, radioactive particles can remain in the atmosphere for a very long time, and in this fashion create a neutron belt. Since neutrons serve to initiate chain reaction fission, it appears that they can cause activation of the nuclear warheads of enemy-guided surface-to-air missiles during their passage through this belt.

Because of their indeed extraordinary possibilities, nuclear warheads are being constantly more extensively applied in guided surface-to-air missiles. This type includes, for example, the guided surface-to-air missile "Nike Zeus", "Nike Hercules", "Talos", "M-2", "T-6", "T-8", and many other nuclear warheads with a TNT equivalent to 1-10 KT. Since the surface-to-air missiles quite often operate over friendly territory in the vicinity of large and important administrative, political and industrial centers, rail and airway complexes, and the like, close attention must be paid to the choice and activation of their warheads, in order to avoid the unwanted effect of nuclear action. Therefore, for each type of surface-to-air missile, the optimal force of the warhead and the minimum altitude of its activation must be determined. It appears that the minimum safe altitude for a nuclear warhead of 1-10 KT is above 5000 meters. However, this altitude limit at the same time is a serious shortcoming of the surface-to-air nuclear warhead, since it gives a great advantage to enemy capacities for inflicting air strikes.

We have now become acquainted with the general characteristics of the basic parts, activation process, and modes of operation of several types of warheads. We have seen that warheads are the unique element which gives a guided surface-to-air missile its destructive properties and makes it the most effective military weapon in contemporary antiaircraft defense. Moreover, the utilization of fragmentation and especially nuclear warheads in these missiles mitigates to a considerable degree the otherwise very severe requirements with respect to the functional accuracy of these guidance and homing systems. Since these systems must direct the missile as closely and as accurately as possible to the target, this is in no way a simple exercise. In some ways the long-range action of the warhead corrects or makes up for a failure of the missile adequately to approach the target, which normally occurs as a result of operational errors in its guidance system and other external factors. Therefore, the necessary number of missiles required to destroy an aerial target with a given probability rises sharply with an increase in the distance of its effective range, and indeed decreases with an increase in the destructive capabilities of its warheads.

It is obvious that nuclear warheads have definitely greater destructive qualities than the others. We know, for example, that only one missile equipped with this type of warhead can destroy all aerial targets which are within an area of a radius of 600-1300 m from the center of the explosion. It should be mentioned that this destructive capacity was not found in any antiaircraft weapon of the past. However, nuclear warheads also have some shortcomings which, to a certain degree, are counter-productive with respect to the full utilization of their military capabilities, to the national security, and to their mass application on surface-to-air missiles.

If they are not to cause great damage to friendly territory, the missiles' action in the case of nuclear warheads must be severely limited with respect to altitude. In practice this means that these warheads cannot be used to reach targets flying at an altitude of less than 5000 meters. It is unnecessary to stress further the consequences which result from this fact, since the air space up to this altitude is not made secure by the effective action of fighter aircraft and missiles equipped with fragmentation warheads. This, on the other hand, renders more costly and more complicated the nuclear antiaircraft defense system. It must only be recalled that the modern means for inflicting an air strike can, from the viewpoint of their tactical and technical possibilities, assume several different flight profiles while undertaking offensive exercises. Contrary to the opinion of many pilots and other military experts, the flight altitude of these weapons at the present time will most frequently be below 5000 m. Nor can we lose sight of the fact that even when these missiles are operating at above 5000 m, friendly territory is to a certain degree contaminated with very dangerous secondary nuclear radiation which can last several hours after the explosion.

Moreover, errors in the functioning of the missiles' launch system, guidance, correction, and self-destruct systems can likewise lead to undesirable results. Thus, for example, if the self-destruct mechanism should fail, the missile with the nuclear warhead, if it misses the target, will fall in friendly territory, and this can sooner or later cause enormous destruction. Similar consequences may also result from errors in the launching or other systems or equipment, or from the operation of certain technical elements during assembly of the warhead, etc.

The high cost of nuclear warheads, together with other more important factors, further multiplies its disadvantages. This, of course, does not mean that the nuclear warhead will not continue to be increasingly utilized for surface-to-air missiles, but that a number of problems will arise in this connection which will tend to conflict with operative, economic, and security requirements, and for which an adequate solution will have to be found in the prospective outlined. Until then, severe restrictions will have to be imposed, not only those discussed above, but others as well, such as the strict observance of rules concerning the storage of missile units, whenever possible and tactically justified, as we-l as that the destruction zone and the actual explosion should be located over uninhabited regions (deserts, oceans and the like) or over enemy territory.

Footnotes

1. to p. 1. In our press, discussions, and the like, the term *"boyeva glava"* ("war (military) head") is ofted used. To my mind this is incorrect and not in the spirit of our Serbo-Croatian language. Obviously in this case it is nothing but a fortunate borrowing of the Russian word *boyevaya*. In support of this one may cite the instances with which I disagree, for example, a wartime captain, but a warship, etc. (Translator's note: This argument is apparently purely semantical, and with no significance in English.)

   The term *"glava"* ("head") itself, which is also well known to us, is also not entirely adequate, since not only is the warhead not always located at a place on the missile which could be indicated as its head, but some surface-to-air missiles can have several (1-3) incompleted warheads, and the warhead itself is composed of many differing (with respect to structure, number, and purpose) components which if they are considered jointly, have very little similarity to the head of a missile. To my mind, the Russian term *boyevaya chast'* (war part) is a much more accurate and complete name for this element of a missile than is the name WH or warhead.

2. to p. 10. According to the nature of their operation, explosives have been classically divided into primary and high explosives.

   The primary or initial explosives are very sensitive and detonate with a light touch or upon being ignited, which means that their energy is easily released. They are distinguished by the fact that their detonating speed quickly achieves a maximum, which is the criterion of their usefulness as activators. Their basic task is to induce the detonation of high-explosive charges, which are not as sensitive to the effects of shock or flame. Then a lesser amount of the latter explosive is needed than if it were used initially. Salts of heavy metals, usually mercury, lead, and silver, are most frequently used as initial explosives.

   High explosives are very different from primary explosives. It is difficult to detonate them by means of shock or initial friction. High explosives ignited by a flame deflagrate quickly in an open space without exploding, while primary explosives detonate immediately. Thus, they are safer when being manipulated, and less sensitive to mechanical effects when they are being assembled. High explosives achieve detonation by means of the detonation of an initial explosive and for this reason are often called secondary explosives. The destructive force of high explosives is much greater than the destructive force of initial explosives.

3. to p. 22. In accordance with published data, the critical mass for an explosive of uranium-235 in the form of a sphere with a diameter of 8.5 cm amounts to approximately 45 kg, and in the case of plutonium-239, to about 10 kg.

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