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CHARACTERISTICS OF AN ATMOSPHERIC NUCLEAR EXPLOSION OVER THE SEA

by

D. P.

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10

EDITED TRANSLATION

CHARACTERISTICS OF AN ATMOSPHERIC NUCLEAR EXPLOSION OVER THE SEA

By: D. P.

Translated under: Contract F33657-68-D-0865

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ABSTRACT → Discussed in the article are the mechanism inherent in a nuclear airburst above the surface of the sea, the various factors involved in a detonation of this type (fire ball propagation, water condensation cloud, underwater shock wave, air shock wave, the effect of heat and penetrating radiation), the possible effect of these and other factors on surface vessels in the detonation zone, and also certain of the more significant differences existing between nuclear explosions above land and above water. Recommendations are given for the proper tactical employment of above-water nuclear airbursts (faster fallout of water vapor at sea than of radioactive dust over land, with consequently less danger to friendly ships and coastal areas in the blast area, and clear, quiet, and warm weather to be preferred for maximum effect and for attainment of partial or complete blinding of ship personnel). Of all the factors discussed, the most dangerous to human beings are the penetration and heat radiation, along with the air shock wave. ( ) ← Tabular data show the interrelation of the four factors of: 1) distance from the zero point in meters; 2) maximum wind current velocity at sea level in km/hr; 3) peak overpressure in kg/cm^2; and 4) peak dynamic pressure in kg/cm^2. Orig. art. has: 1 table and 2 figures.

OPERATIONAL SKILLS AND TACTICS OF NAVAL FORCES

CHARACTERISTICS OF AN ATMOSPHERIC NUCLEAR EXPLOSION OVER THE SEA

D.P.

An atmospheric nuclear explosion over water is in general similar to that over land. Hence, there is no need for detailed description of its essential nature, course and general radiation factors acting on the surroundings. However, it is indicated to discuss specific characteristics flowing from the fact that the explosion takes place over water — a liquid and moving body which is capable of vaporizing.

The first characteristic of every explosion of a nuclear charge in the atmosphere will be the formation of a hot, luminous gas sphere of large diameter (for a charge of 20 KT, up to 500 meters). At an explosion height which is less than the maximum radius of the sphere (from 0 to 200 meters) its lower limit may reach the surface of the water, causing a thermal vaporization effect and the mechanical effect of displacing the water under point zero. Thus, a steaming crater of water may form, reaching even to the bottom of the sea, with the latter 40-60 meters deep. The formation of a large mass of water vapor and of the corresponding water crater is the principal characteristic of an atmospheric nuclear explosion over water. This phenomenon has a decisive effect on the course of other nuclear explosion factors, and particularly on the underwater shock wave and on the tidal wave, as well as light and penetrating radiation.

After formation of the fireball, from 0.1 to 2 sec after the explosion, the bow of the atmospheric shock wave forms in the air and propagates over the water at a speed of up to 250 m/sec. The impact of the atmospheric wave front against the water surface causes formation of a high wave, pushed out from the water crater. Simultaneously, an underwater shock wave forms. Moreover, at the instant of impact of the atmospheric wave front against the water, a secondary (reflected) shock wave is formed. It is much weaker than in an explosion over land, because the surface of the water offers less resistance.

Every surface vessel located within the reach of the atmospheric nuclear explosion over water is first hit by the front of the underwater shock wave (weak), then by the front of the atmospheric shock wave, and finally by the crest of the water wave. The above-cited phenomena (factors) which arise within 3 seconds after a 20 KT explosion are shown in Fig. 1.

Simultaneously with the above phenomena, after the first second following the nuclear explosion, there is gradual formation of a condensation cloud which contains a large amount of radioactive substance. The condensation cloud forms during rarefaction of the air (suction effect) and with a drop in pressure and temperature below normal for the given instant. During this time, the water vapor which forms at the instant of contact between the fireball and the water is drawn into the interior of the rarefaction zone, where water-vapor condensation occurs to form a disk-shaped cloud. This cloud is completely dispersed during the next several seconds, because droplets of condensed vapor following the shock wave enter the heated-air zone and begin to change into steam which gradually rises upward.

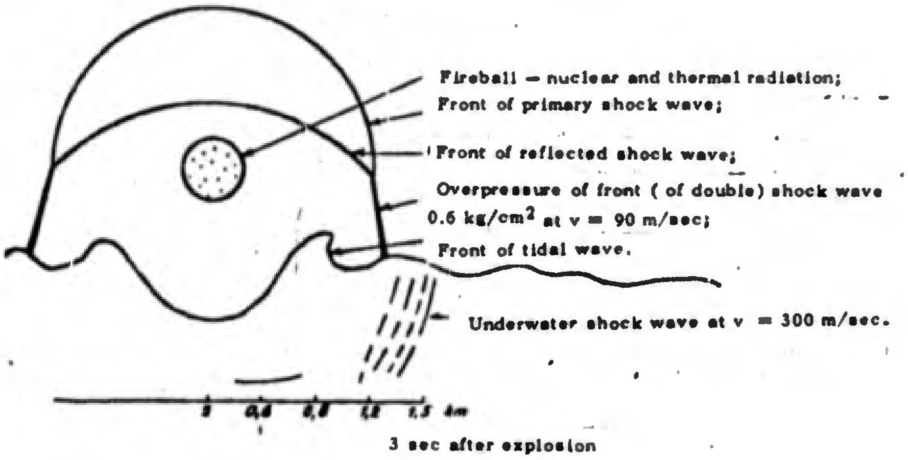

Fig. 1

The condensation cloud does not reduce thermal radiation, because it forms after emission (in 1.5-2 sec) of most of its thermal radiation by the fireball.

The further development of the explosion is less violent. The individual processes, derivative from the above described factors, occur in the atmosphere and on the water in accord with the laws of nature. Within 3-4 seconds from the instant of explosion, the heated air current (the remainder of the fireball) begins to rise upward. The fireball no longer glows, nor emits thermal rays, but gradually transforms into a mushroom of water vapor and a radioactive cloud.

After 10 seconds, the front of the atmospheric shock wave is about 4 km from point zero, exhibiting an overpressure within the limits 0.1-0.2 kg per 1 cm^2, which is enough to cause minor injuries to the human body and damage to the weak superstructures of ships. Rising, the strong currents of heated air (entering currents) form a high (to 1.6 km) column of water vapor and small water droplets. It ends in a characteristic mushroom, containing a cloud of heated water vapor and small water droplets saturated with radioactive substances. The state of the principal elements of the explosion is shown in Fig. 2.

In the meantime, we have the effect of the water being drawn up and completely filling the water crater, and even of the bulging of the surface of the water beneath point zero, which leads, in turn, to successive tidal waves of smaller force and range.

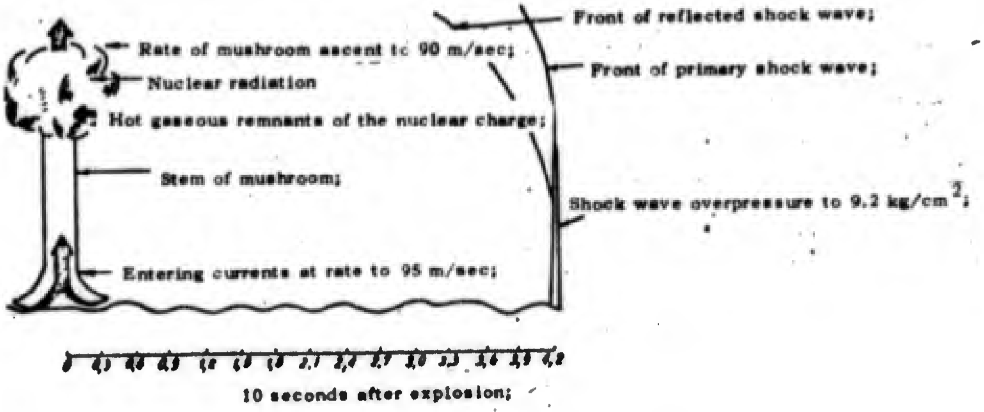

Fig. 2

After 30 seconds, the "mushroom" of the radioactive cloud may reach an altitude up to 2.5 km. It will continue to rise, slowly cooling, which will cause considerable condensation of water vapor saturated with radiating substances and then fall to the surface of the water in the form of radioactive rain. Unlike an overland explosion, in an explosion over water the radioactive precipitation will have a much wider range and will be more violent, because precipitated water vapor has a greater tendency to fall downward than dust formed during an explosion over land. In this connection, atmospheric nuclear explosions over water can be conducted without great fear of nuclear contamination of your own vessels and coast, even if the winds blow in their direction. Explosions can be set off at distances ensuring safety from thermal and mechanical effects.

Atmospheric explosions over water are most effective in rainless weather and with a relatively calm water surface. However, they are less effective in cloudy weather, fog, rain, storm or squall. They are particularly effective during a warm, cloudless and windless night. Then, the full effect of thermal and mechanical action (shock wave) is supplemented by the very strong effect of temporary or permanent (partial or complete) blinding of people. In range, this effect far exceeds the radius of thermal and mechanical action, because radiation of light is absorbed by air and water vapor only to a very small degree, and it is strengthened and reflected by the calm water surface. In this instance the water plays the role of a mirror reflecting light rays. The blinding effect is particularly dangerous because it renders incapable of engaging in combat even those crew members who, while on deck, were not affected by thermal or mechanical action of the nuclear explosion.

Every vessel located within the range of a nuclear explosion will be exposed to complicated ray-producing effects, as well as to thermal and mechanical effects. The first to act is penetrating radiation; then comes the flash (light and thermal radiation), followed by the underwater shock wave, relatively weak, but perceptible and capable of inflicting slight damage (deformation) to ship hulls. Then, in turn, ships are struck by the front of the atmospheric shock wave and by the front of the tidal wave which moves outward from the center.

Subsequently, suction of water and air under the mushroom of the nuclear explosion is followed by the reflected (centripetal) atmospheric shock wave and the tidal wave.

Among the above factors, the most dangerous to people and ships is penetrating radiation, the atmospheric shock wave and thermal radiation. The tidal wave and the underwater shock wave are less dangerous.

In this article we shall discuss only the effect of the atmospheric shock wave and thermal radiation. However, the effect of the tidal wave and the underwater shock wave will be discussed in the next issue of *Przeglad Morski* in an article on the subject of underwater nuclear explosions.

Penetrating radiation in an atmospheric nuclear explosion over water does not differ in any way from similar radiation in an atmospheric nuclear overland explosion, for all forms of nuclear explosions.

The atmospheric shock wave acts mechanically and its damaging effect is governed by the overpressure, underpressure or dynamic pressure peaks, which are functions of the speed of the air current and the air density at the front of the shock wave. For very great air-current speeds (over 1900 km/hr) dynamic pressure is greater than overpressure. However, at air speeds below 1900 km/hr and with the overpressure peak below 5.5 kg/cm^2 (at sea level), dynamic pressure is lower than overpressure. The dynamic pressure and overpressure peaks slowly diminish with increasing distance and drop in air speed. The greater the distance, the weaker the peaks, and the dynamic pressure peak drops at a much faster rate than the overpressure peak. Table 1 illustrates this example.

TABLE 1

Distance from point zero, in meters	Maximum air speed at sea levl, in km/hr	Peak of overpressure, kg/cm^2	Peak of dynamic pressure, kg/cm^2
400	2100	5,04	5,6
500	1760	3,5	2,8
600	1200	2,1	1,3
700	850	1,4	0,6
1000	530	0,7	0,14
1250	400	0,5	0,06
1600	300	0,35	0,04
2000	130	0,15	0,01
2500	80	0,08	0,005

We can conclude from Table 1 that at air speeds in the range of 1700 km/hr, the peaks are basically equal, 3.5 and 2.8 kg/cm^2, respectively. However, with a fourfold decrease in air speed (by 400 km/hr), the overpressure peak drops by a factor of almost 7 (0.5 kg/cm^2) and dynamic pressure by a factor of 47 (0.06 kg/cm^2). When the front of the shock wave reaches a ship, both values (overpressure and dynamic pressure), encountering resistance, increase sharply, and then decrease.

After passage of the shock wave front, a zone of rarefied air appears, causing a drop in pressure below atmospheric, i.e., an underpressure wave begins. During the negative phase of underpressure, dynamic pressure is very low and acts in the opposite direction. This has a negative effect on the superstructure of ships and on nonelastic materials. This is a complex process, affected by the force of the wave, the position of the ship in relation to the front, the height and shape of the sides and superstructures, and resistance of the materials of which the ship is built.

Damage is considerably affected by the force of dynamic pressure and duration of its effect on the ship. Most exposed to its effect are the sides and decks of the ship. With a vertical strike of the shock wave, there is a rebound which causes a secondary overpressure, which can be 2 to 8 times greater (depending on the angle at which the wave strikes) than the primary overpressure. The shock wave bends and seems to entwine the ship, transferring the pressure to the deck and the opposite sides of the ship.

Since the pressure rebounding from the bow is greater than the pressure exerted on the deck, it soon changes into static pressure which is derivative from overpressure and dynamic pressure. The time of frontal overpressure abatement equals the time required for the passage of the suction wave from the rim of the bow to the center of the deck and back again to the rim. Then comes a brief period of low pressure caused by a whirlpool at the rim of the bow during the process of bow flexure.

The shock wave reaching the opposite side of the ship bends at the rim and spreads downward along it, i.e., in the direction of the water. When the overpressure on the opposite side reaches the value of the wave coming down on the bow, the process of ship-bending can be considered finished; this is followed by a drop in pressure below normal. Then the rebounding shock wave acts on the ship in an identical manner, but in the opposite direction and with a lower pressure force.

The shock wave causes bending of the sides and deck of the ship inward and outward and vibration of the sides and superstructure of the ship to exceed the resistance of the structural material of the ship. As a result of the shock wave effect, a ship can be completely crushed and broken, or partially damaged, depending on the distance from point zero, the position, size and dynamic resistance.

In connection with the above, it can be concluded that under equal conditions and factors (distance from point zero, type, size and strength of ship, etc.), the greatest damage from an atmospheric shock wave will be inflicted on motionless (anchored) ships which suffer a vertical strike of the wave front from the side.

Thermal radiation of the fireball of an atmospheric nuclear explosion consists of heat waves of different length, and namely: short (ultraviolet), medium (visible radiation) and long (infrared). The short waves have the shortest range, since a large part is absorbed or dispersed during passage through the atmosphere.

Thermal radiation comes from the surface of the fireball, which emits radiation in two phases (peaks). The first peak of radiation contains a majority of the ultraviolet rays, formed within about 0.0001 sec after the explosion, when the temperature of the fireball reaches about 15,000°C. Its duration is very short, hardly a fraction (to 0.0004) of a second. The total quantity of energy emitted during the first peak is minimal in relation to the total thermal energy of the explosion, because of the very short duration of emission and strong absorption of ultraviolet rays by the atmosphere. Ultraviolet rays are harmful to humans from the biological viewpoint, and particularly dangerous are pulses of thermal radiation emitted at the instant of maximum fireball temperature. This is precisely the instant of highest thermal radiation intensity and maximum speed of transfer (at the appropriate distance) for the thermal energy of the explosion. Shortwave radiation causes congestion of subcutaneous tissue, and in severe cases produces disturbances in the human body similar to severe sunstroke. Subsequently, after 0.13 sec from the instant of explosion, at the instant of separation of the shock wave from the fireball surface, the temperature drops to 2100°C, reaching the first minimum. After this the fireball surface temperature begins to increase, because of a gradual flow of thermal energy from the isothermal region, all the way to equalization of the temperature between the surface and center of the fireball. The temperature reaches the second peak (second maximum) of about 8000°C within 0.15 sec after the explosion, producing a second radiation peak.

The amount of thermal radiation emitted during the second peak is large and basically responsible for the degree of human skin burn or for fire.

Following this, the fireball begins to cool. Within a few seconds temperature drops to 1000°C, and then even lower, until it reaches the temperature of the surrounding atmosphere. After about 15 minutes the ball disappears. It changes into a radioactive cloud.

The effective range of thermal radiation which produces burns of the 1st, 2nd and 3rd degree increases out of proportion to the increase in the force of the explosion. For example, a nuclear explosion of 1 KT force, taking place at an altitude equal to the maximum fireball radius, with good atmospheric visibility over 15 km and absence of fog or precipitation, can cause 3rd degree burns over a distance of up to 600 m from point zero; a nuclear explosion of 10 KT force, over a distance of 1700 m, and of 100 KT force over 5000 m. In practice, a 100-fold increase in the force of an explosion will be accompanied by only a ninefold increase in distance to produce 3rd-degree burns. However, in foggy weather, the distance of the thermal radiation effect will be smaller and proportional to the degree of fogginess of the air. In complete fog and low clouds with a maximum concentration of water vapor, the distance of thermal radiation effect to produce 3rd-degree burns can be less than half the distance above.

Ships constructed of metal are generally more resistant to thermal effects. The greatest danger of thermal radiation threatens persons on open decks of ships. There is, however, a possibility of taking shelter from thermal radiation during a fraction (about 0.2 sec) of a second from sighting the emerging fireball. The feasibility of this depends on the distance between the ship and point zero of the explosion, as well as, in large degree, on the physical agility of the crewmen and the speed of their reflexes to visual excitation (result of training). Thermal radiation reflects in considerable degree from polished and white objects, which provides additional opportunity of protection against it.