Emergency medicine

Physical phenomena occurring during nuclear explosion in terms of the effects of ionising radiation to the human body

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Received: 2010.12.20 • **Accepted:** 2011.03.02 • **Published:** 2011.03.20

Summary:

The comparison of the yield of the burst of conventional weapons 'charge and mass destruction weapons' charge. Striking effect of shock wave, thermal and penetrating radiation on human body. The effects of shock wave on living organisms and the inanimate matter. Direct and indirect effects of thermal radiation, i.e. skin burns, eye damage. Striking effect of ionising radiation.

Key words: effects of ionising radiation to the human body, shock wave , thermal radiation

Introduction

Since the dawn of time human has been living in contact with ionising radiation. It is in the ground where we walk, in the air we breathe and in food we eat. People are constantly being bombarded by cosmic rays. Moreover, we have to deal nowadays with radiation produced by human beings e.g. X-radiation, which significance in medicine we are aware of. Greater exposure to harmful ionising radiation occurs in some cases. This is particularly true for people working in direct contact with radiation and hence they are exposed to higher doses than average people. Simultaneously, it should be remembered about other situations which threaten with irradiation as well as contamination posing ecological problem and health problems.

This include risks arising from irradiation connected with environmental contamination by radioactive substances coming from:

- industrial radioactive waste (global problem);
- accidental contamination (theft of isotopes, radioactive material smuggling especially from the former CIS);
- nuclear weapon and weapon of reinforced radiation and their striking factors;
- shock wave resulting from generating huge pressure differences;
- thermal radiation such as the emission of high temperatures after nuclear explosion;
- ionising radiation constituting 15% of released energy;
- radioactive contamination of the land associated with early and late nuclear fallout;
- accidents of reactors in nuclear power plants which occurred, are and will be occurring, especially in case of reactors with outdated technology e.g. RMBK reactors.

The explosion of nuclear ammunition differs from the burst of conventional ammunition in the following features:

1) the yield of nuclear burst is thousands or even millions times greater than the yield of burst of conventional ammunition. The energy of the explosion of nuclear ammunition is compared to the energy of explosion of equivalent mass of trinitrotoluene (TNT). On this basis the yield

of nuclear ammunition is expressed with TNT equivalent either in kilotons (thousands of tons of TNT; kt) or megatons (millions of tons of TNT; Mt). According to the explosion energy, nuclear bursts can be divided into the following types: very low-yield (up to 1kt), low-yield (1 - 10 kt), medium-yield (10 - 100 kt), high-yield (100 kt - 1 Mt), large-yield burst (more than 1 Mt);
2) during the nuclear burst more energy is released in form of the shock wave and thermal radiation;
3) nuclear burst is accompanied by emission of neutron and gamma radiation as well as by radioactive contamination;
4) the energy of nuclear or thermonuclear burst comes from atomic nuclei and is released as the result of the fission of heavy nuclei or fusion of nuclei.

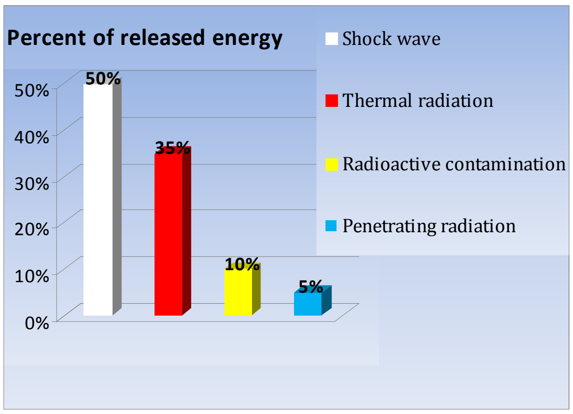

Figure 1: The division of energy released during thermonuclear air burst.

At first, during the nuclear burst blinding flash occurs which may be the cause of retinal and corneal burns. A fireball is formed almost simultaneously with the flash. Two seconds after 1 Mt burst its diameter reaches 2.3 km and after 6 Mt burst it reaches 6 km. Radiation is emitted from the fireball in two phases.

During the first phase short-lasting emission of ultraviolet radiation occurs, which lasts only for a fraction of a second, followed by a few seconds emission of infrared radiation. Almost at the same time as the flash, a shock wave is formed as a result of sudden rise in pressure, propagating with the speed of sound. After the wave of overpressure passes, the wave of under-pressure occurs, leading to numerous ruptures of tissues and blood vessels as well as the entire organs, especially those, which contain large amount of gasses and fluids (e.g. lungs, intestines, brain, bladder, gallbladder) and parenchymal organs (e.g. liver, spleen) or large arterial trunks.

Two types of factors can be distinguished in the striking effect of nuclear weapon i.e. immediate factors (shock wave, thermal radiation, penetrating radiation), which striking effect occurs during the burst or shortly after the explosion and delayed striking effect (radioactive contamination).

Striking effect of the shock wave

Shock wave is formed as a result of large pressure difference occurring during the explosion. Highly compressed air spreads from the ground zero to the circuit with supersonic speed, simultaneously undergoing rapid rarefaction. Therefore, two periods of shock wave action can be distinguished: overpressure period and under-pressure period.

The front part of overpressure zone is called a shock wave front. When the shock wave front reaches certain point, rapid rise in pressure, temperature and density of the air occurs. Afterwards, the pressure falls until the under-pressure is produced. The overpressure zone moves to the under-pressure zone and the air moves towards ground zero. The velocity of air moving in the opposite direction to the shock wave is several times lower than the velocity of the shock wave front spreading. Striking effect of the shock wave depends on the value of the pressure on its front and is expressed by Pa (kG/cm^2).

Three damage zones are distinguished in accordance to the value of overpressure on the shock wave front:

1) **Zone I.** Severe damage zone covers the area where the overpressure exceeds 100 kPa (1 kG/cm^2). In this zone industrial and residential buildings are completely destroyed, whereas shelters, underground utility and energetic system are damaged. People and animals will die, if they are not hidden in the shelters.

2) **Zone II**. Moderate damage zone covers the area where the overpressure amounts from 100 to 30 kPa (1 - 0.3 kG/cm^2). Structures and buildings are damaged to various degree, whereas shelters and underground utility and energetic systems should not be damaged. People and animals, found in damaged buildings, may be buried by debris or suffer from physical and thermal injuries. Mass fires i.e. firestorms occur.

3) **Zone III**. Light damage zone covers the area where the overpressure amounts from 30 to 10 kPa (0.3 - 0.1 kG/cm^2). In this area wooden houses are partially or completely destroyed, whereas brick buildings are damaged to moderate or small extent. People and animals will suffer from minor physical and thermal injuries. Numerous fires occur.

Two types of the shock wave effects on people are distinguished i.e. direct and indirect. Direct effect is caused by rapid and large pressure differences (overpressure and under-pressure). Indirect effect involves striking the entire body with fragments of various objects or movement of entire body. Death occurs die to paralysis of centres in medulla oblongata - at first the paralysis of respiratory and vasomotor centres - or due to air emboli, which occur as a result of damage to alveoli and small blood vessels in the lungs. The injuries of people due to direct effect of the shock wave can be light, moderate, severe and very severe.

Table 1: Radius of damage zones in the area of nuclear strike [km]

Damage Zone	Radius of zones after the burst of the following yields				
	0,5 Mt	1 Mt	5 Mt	10 Mt	20 Mt
Severe	3,2	4,0	6,8	8,6	10,7
Moderate	4,4	5,4	9,3	11,7	14,7
Light	5,5	7,0	12,0	15,0	19,0

20 - 40 kPa overpressure (0.2 - 0.4 kG/cm^2) causes light injuries (contusions, limbs dislocations, temporary hearing impairments). 40 - 60 kPa overpressure (0.4 - 0.6 kG/cm^2) results in moderate injuries (nose bleedings, bleeding from ears, limbs fractures, severe contusions of the entire body, hearing damage). 60 - 100 kPa overpressure (0.6-1.0 kG/cm^2) effects in severe injuries (bone fractures, nose bleedings, bleeding from ears, internal organ damage). Overpressure over 100 kPa (1 kG/cm^2) causes very severe injuries usually resulting in death.

Table 2: Range of overpressure of the shock wave dependent on the yield of airburst [km]

Overpressure in kPa [kG/cm^2]	Range of the shock wave during burst of the following yields:			
	20 kt	1 Mt	5 Mt	10 Mt
20 (0,2)	2,4	8,9	15,1	19,2
30 (0,3)	2,0	7,4	12,6	16,0
40 (0,4)	1,6	6,6	10,0	12,8
50 (0,5)	1,2	4,4	7,6	9,6
100 (1)	0,6	2,2	3,7	4,8

Indirect damages caused by the shock wave are the consequence of striking with fragments of various objects dependent on the velocity of the fragments, the angle of their incidence, size, shape, density, weight and type. The spot of the body vulnerable to the strike of the fragments has also crucial meaning.

Movement of the entire body due to the indirect effect of the shock wave depends on the physical parameters of the shock wave and the position of the body relative to the direction of its propagation as well as it depends on which part of the wave hits the obstacle (head, back, chest, limbs).

Shock wave is formed during a fraction of a second after the burst and its direct effect covers the period of seconds depending on the yield, nature, area of the burst and the landform features.

During a ground burst of a yield of 1 Mt, the duration of the shock wave effect in 1 km distance amounts to 1s, in 5 km distance to 2.7s, whereas in 10 km distance it amounts to 4.5s. The duration of peak overpressure ranges from 0.5 to 1 s. The under-pressure period lasts longer, usually few seconds. The velocity of the wave moving decreases as the distance from the values significantly exceeding the sound speed to the speed of sound waves propagation increases.

Table 3: Time of occurrence of peak overpressure after air burst [s]

Distance in km	Time of occurrence of peak during burst of a following yield:				
	1kt	10 kt	100 kt	1 Mt	10 Mt
1,6	4,3	3,6	3,7	2,5	1,5
3,2	9,0	8,1	8,1	6,5	5,0
4,8	-	13,0	12,0	11,0	9,5
8,0	-	-	21,0	20,0	16,0
11,0	-	-	30,0	28,0	26,0
16,0	-	-	-	42,0	37,0
32,0	-	-	-	90,0	83,0
48,0	-	-	-	-	130,0

Striking effect of thermal radiation

Following directly a nuclear explosion, thermal radiation has a spectrum of ultraviolet, visible, low-energy X radiation. The radiation is immediately absorbed in several meters layer of the air and as it is not propagating further, it does not constitute a significant striking factor.

The emission of thermal radiation energy occurs in two phases, each having its peak of emission. As the first phase lasts tenths of a second after the burst and emitted energy constitutes only 1% of thermal radiation energy, it does not pose a considerable threat. Second phase of thermal radiation emission is an important factor of striking effect due to the duration and percentage of total energy at the second emission peak. It may last from several to dozens of seconds (e.g. in case of air burst thermal pulse lasts circa 0.3s for a charge of 1 kt yield, circa 10 s for a charge of 1 Mt yield and circa 30s for a charge of 10 Mt yield). At that time approximately 99 % of total energy is released. Thermal radiation of a second peak consists of visible radiation and infrared radiation causing fires and burns of people and animals.

Indirect and direct effects of thermal radiation can be distinguished. Direct burns otherwise known as flash burns are caused by flash of thermal radiation coming from fireball. Indirect burns results from the contact between the victims and flames of the fire, hot gases and liquids.

Flash burns occur on the uncovered surface of the body exposed to the effects of thermal wave. Owing to the fact that thermal radiation causing flash burns is emitted during a short time for charges of low yield (below 1 kt), these burns are superficial. In case when the yield of a charge exceeds 1 kt and thus the duration of thermal wave emission is prolonged, human body is exposed to the same effect of high temperature as in the case of flames. Depending on the yield of a charge and distance for the burst area, body may be charred or partially paralysed as a result of striking effect of thermal radiation.

In addition to skin burns, flash of nuclear explosion may cause eye damage. Being a result of retinopathy, such damages reveal themselves in form of temporal or permanent blindness.

Permanent damages i.e. retinal burns result in direct effect of the thermal wave. The extent and degree of temporal damage, caused by visible radiation of high intensity, depends to the large extent on the distance from the burst and the weather conditions. Research conducted on rabbits has revealed that sight damage may occur at greater distances, especially at night from the burst than skin burns.

Tests of nuclear air burst of a yield of 1 Mt conducted at night at the altitude of 7.5 km showed that retinal burns occurred at a distance of 550 km from the burst area. Other experiment conducted during the day revealed the retinal burns at the distance of 60 km. However, radius of the zone of eye burns decreased to 5 km with low transparency of the air.

Firestorm caused by indirect effect of thermal radiation will have huge impact on the size and type of loss after the explosion. Fierce fires resulting from thermal wave will move centrifugally with velocity of 200 - 300 km/h, whereas burning buildings, fuel tanks or other flammable buildings will create long-lasting rise in air temperature up to several hundred degrees. Such conditions will result in numerous burns caused by flames or hot gases.

The yield and type of nuclear explosion, distance from the centre of the burst and weather conditions are significant factors which influence the range of striking effect of thermal radiation. Three degrees of burns can be distinguished due to the strength of thermal radiation. First-degree burns i.e. superficial burns, redness and swelling of coating occur as a result of pulse of energy ranging from 2 of 4 cal/cm^2. Blisters i.e. second-degree burns are caused by pulse of energy ranging from 4 to 10 cal/cm2. The effect of a pulse of 10 to 15 cal/cm^2 results in extensive ulceration, necrosis, skin and deeper tissues charring i.e. third-degree burns. Thermal pulses of thermal energy above 15 cal/cm^2 cause charring of extensive body surface or the entire body.

Table 4: The range of thermal pulse after nuclear explosion of various yield [km]

Thermal Pulse (kG/cm^2)	The range of thermal pulse during the explosion of the following yields:			
	20 kt	1 Mt	5 Mt	10 Mt
2	4,0	26,8	37,0	51,0
4	2,8	18,6	33,5	41,0
6	2,4	16,6	29,5	37,0
10	1,8	14,6	23,0	30,5
14	1,5	11,2	17,5	28,0
16	1,3	10,0	16,5	26,0

Striking effect of ionising radiation

The emission of ionising radiation of huge intensity is the third basic effect of nuclear burst. Two striking factors are distinguished, which nature is constituted by ionising radiation, external penetrating radiation from a distance (circa 5%) and the radiation emitted by radioactive substances of the contaminated area (circa 10%) as the external irradiation, internal and external contamination.

Penetrating area is a radiant flux of gamma and neutron radiation emitted from the area of nuclear burst. Reactions of fission and fusion (or both processes), taking place during the nuclear burst, are the source of such radiation.

The striking effect zone of penetrating radiation of nuclear burst, especially of medium and high yield, does not exceed the striking zones of shock wave and thermal radiation. Injuries caused by thermal radiation and mixed injuries (so-called mixes) caused by coactions of shock wave, thermal and penetrating radiation will prevail in this zone. In case of bursts of neutron charges and charges of increased effect of penetrating radiation (ERW), the range of striking effect of penetrating radiation will considerably exceed the striking range of the shock wave and thermal radiation.

The emission time of gamma radiation does not exceed few seconds (for bursts of medium and high yield) and 10 - 15 seconds for bursts of very high yield. The emission time of neutron radiation does not exceed 1 second. The range of striking effect of penetrating radiation is dependent on the type of nuclear charge and its burst yield.

The average radiation dose on the entire body, which was received by Poles during the first year after Chernobyl (according to UNSCEAR), amounted to 0.27 mSv. It constituted 11% of annual natural radiation dose. During the entire life Poles will receive on the whole body dose from the Chernobyl fallout amounting on average to circa 0.9 mSv i.e. 0.5% of a dose, which in the same time they will be radiated from natural sources amounting to 168 mSv. Circa 74% of this dose on the entire body came from ^{137}Caesium, 20% come from ^{134}Cs, 1% from ^{131}Iodine and circa 5% from other isotopes.

Such low dose of the Chernobyl contamination on the entire body will not result in any harmful or favourable, or noticeable charges of health of population in our country. Radiation dose from ^{131}I absorbed by the thyroid gland was significantly higher. In western less contaminated provinces amounted from circa 2 to 30 mSv in case of children aged one year. In eastern and more contaminated provinces the dose amounted from 10 to 90 mSv. Maximal doses amounted to almost 200 mSv at nearly 5% of children (with iodine prophylaxis). Iodine prophylaxis decreased the doses delivered to the thyroid of children approximately of a half.

At the areas, where the action was started earlier, the dose could have been decreased even five times. Circa 70-80% of radioiodine in children thyroid was delivered in food (mostly from milk). Only 20-30% of radioiodine was delivered to the thyroid via inhalation. The maximum concentration of ^{131}I in milk occurred in most regions after 5th May. Therefore, even late prophylaxis has given a favourable effect. Had the iodine prophylaxis not been conducted in Poland, the radiation dose delivered by ^{131}I radiation to thyroid of circa 5% children i.e. 500 000 would exceed 1000 mSv. Thyroid cancer incidence rate after the above-mentioned and higher doses equals circa 1% in Belarus.

If the situation looks the same in Poland, it can be assumed that iodine prophylaxis action saved circa 5000 Polish children from this disease. According to the data from Mayo Clinic in Rochester, Minnesota, complete recovery of children from thyroid cancer occurs at almost 100% cases. It is a good prognosis for 682 children with thyroid cancer in Belarus, Ukraine and Russia. Many of them are treated in Western countries. As a result of iodine prophylaxis action 18.5 million people including 95% children and teenagers took blocking dose of Lugol's iodine solution. It was the first such great prophylaxis action performed during few days in the history of medicine. It started after 13 hours after the decision was taken. The action proves high organisational skills and ability to improvise of Poles.

For the comparison it should be noted that after the power plant accident in Three Mile Island near Harrisburg in Pennsylvania in 1979 American government started to provide local inhabitants with iodine pills produced ad hoc after 4 days after the accident. This illustrates the logistic difficulties of such action, which largely contributed to the fact that other European countries did not perform it even though some of them were more contaminated than Poland was.

In Europe there was simply neither ample supplies of iodine pills for endangered population nor the chances for their immediate production and distribution. Our success resulted from enterprising plan and innovative idea of the Ministry of Health. It was decided not to use iodine pills, which we did not have, but to prepare in every pharmacy Lugol's solution well-known to all pharmacists. The supplies of iodine and potassium iodide essential for its production in pharmacies were significantly above the needs.

Table 5: Table 5 presents the examples of the range of the effect of penetrating radiation. [km]

Type of charge	Yield of a charge	The range of the effect of penetrating radiation [km]
Nuclear charge (fissionated)	20 kt	ca 2
Thermonuclear charge	1 Mt	ca 3,5
Thermonuclear charge	10 Mt	ca 4
Thermonuclear charge	20 Mt	ca 7
Nuclear charge (fissionated, air)	1 kt	ca 1
Neutron bomb (air)	1 kt	ca 1,5

Epidemiological studies (the largest ever conducted in Poland) conducted by Professor Janusz Nauman from Medical Academy in Warsaw and his team composed of the most eminent Polish endocrinologists and radiologists has revealed that the 'extrathyroid' side effects after the administration of Lugol's solution (nausea, headaches and itchy skin occurred in circa 5% cases. Very small children vomited sometimes, especially those that were administered with iodine solution instead of Lugol's solution.

No age groups showed 'intrathyroid' side effects of prophylactic iodine doses. The studies conducted in 1989 - 1990 did not demonstrated increased incidence of thyroid cancer. Researches of the Institute of Oncology revealed no growth of thyroid cancer and leukaemia until 1995. Very important, secondary result of studies conducted by the team of Professor Nauman was finding the presence of endemic goitre at inhabitants of large area of Poland caused by severe iodine deficiency in our diet.

The deficiency started around 1980, when the iodination of table salt was ceased. As a result of these studies iodination of food was restored, what should contribute to the improvement of population health.

Striking effect of contamination with radioactive substances

When the shock wave reaches the ground, its reflection occurs. The primary and reflected wave meet and form so-called Mach wave. At this moment a vertical string of air is formed, which when carrying off the remains of the matter forms a chimney connecting with the remains of the fireball. The latter cools down, stop shining, but still hot rises and after few minutes it reaches a height over 10 km. Nuclear fission products and bomb debris, remaining inside the ball in the vapour state, condense and form highly radioactive cloud. A mushroom cloud is formed after 30 s from ground zero and after 120 s it assumes 'mature' shape.

Local fallout. Radioactive cloud rises at the height of several to several dozen kilometres, moves with the wind and gradually spreads in the air. Radioactive substances fall from the cloud forming a local fallout. The strip of the land in the direction of the motion of the cloud is called the trace of the radioactive cloud.

Worldwide fallout. After air and ground bursts of high yield, 20% of formed radioactive substances are drawn up to the stratosphere creating worldwide fallout in the least expected area and time, whereas the remaining 80% forms a local fallout in the nearest vicinity of the burst.

The difference between striking effect of radioactive contamination after ground bursts (water) and air bursts lies in the fact that during the ground burst radioactive cloud is formed and contains more substrate on which the burst occurred (e.g. ground with a predominance of silica and calcium or water). During the air burst, the fireball does not contact the ground (water) and as the consequence the updraughts pull into the cloud less particles. Radioactive substances found in a radioactive cloud can be derived from three sources: nonfissioned nuclear fuel, induced radioactivity, fission products.

Quantitative relation between individual sources of radioactive substances in the fallout depends on the type, yield, place and time that has elapsed since the explosion (e.g. fission products can be found in larger quantities after bursts of three-degree nuclear charges, otherwise known as combined bursts). In total circa 700 isotopes of 35 chemical elements are created as a result of fission and secondary changes. Circa 250 are stable isotopes (nonradioactive) and the remaining 450 isotopes are radioactive. They constitute a set of isotopes of 35 elements located in the periodic table of the chemical elements with atomic numbers (Z) from 30 to 64 (from zinc to gadolinium) and mass number (A) from 65 to 160.

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