

Nuclear Weapons - Consequences for the Biosphere in Case of Their Potential Use

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Abstract—The study aims to investigate nuclear weapons - consequences for the biosphere in the case of their potential use. Understanding the devastating impact of nuclear weapons on the surrounding biological world, infrastructure, and cultural and material values poses a significant challenge for scientists. Modern theories explaining the destructive factors of nuclear weapons do not provide completely satisfactory answers and remain incomplete. This report will examine the dangers associated with the detonation of nuclear munitions, their various types, and the resulting destructive effects on our surrounding environment, as well as some of the main methods of protection.

Keywords— nuclear ionizing radiation, natural and artificial radioactivity, plants

I. INTRODUCTION

After the detonation of atomic bombs, radioactive fission products of heavy nuclei and part of the unfissioned nuclear fuel enter the atmosphere. The entry of U-235 and Pu-239 occurs because the utilization coefficient of nuclear fuel never reaches 100%.

With the explosion of a thermonuclear bomb, the amount of fission products increases proportionally to the bomb's power. In an air nuclear explosion, an interaction process occurs between atmospheric oxygen and nitrogen, forming nitrogen oxides. An atomic bomb with a TNT equivalent of 20 megatons can form 50,000 to 500,000 tons of nitrogen oxides, which create nitric acid and lower the pH (acidity, alkalinity) of rainwater, i.e., acidify it.

The speed of transport of radioactive products can be significant. For example, in the city of Troy (USA), located 3,450 km from the Nevada test site, a powerful hurricane occurred 36 hours after a nuclear explosion test [1], leaving a trail of radioactive material along its path. A. Zitkus [2] found that fission products from experimental explosions

conducted in Nevada and the Marshall Islands reached Germany in 10-20 days. Fission products from the same explosion can appear in the same place several times after a significant interval.

The gravitational deposition of smaller particles is hindered by various laminar and turbulent air mass flows that exist in the atmosphere. The descent of particles of all sizes in the atmosphere is always accelerated in the precipitation zone. It has been established that the amount of radioactive substances falling on the soil significantly increases on rainy days. In the explosion of high-power bombs and in cases where explosions are carried out at high altitudes, a reservoir of long-lived radioactive isotopes is formed in the stratosphere.

The speed of transition of radioactive products from the stratosphere to the troposphere probably depends on the size of the particles and the height at which they were ejected. In mid-latitudes, the speed increases in spring. Another, albeit significantly smaller, source of environmental pollution is the waste released from nuclear industry enterprises. The disposal of this waste is a very important problem, the proper resolution of which will prevent a number of undesirable consequences. For example, the burial of radioactive waste in seas and oceans can cause gradual contamination of water, marine flora, and fauna.

The greatest danger is posed by long-lived isotopes strontium-90 (Sr-90), cesium-137 (Cs-137), cesium-144 (Cs-144), and to a lesser extent, ruthenium-106 (Ru-106). During nuclear explosion tests in the atmosphere, several tens of megatons of fission products were released. According to some data, by the end of 1958, the total amount of Sr-90 and Cs-137 formed was 9.2 and 16.5 MCi, respectively.

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From the atmosphere, fission products enter the soil, marine, and freshwater bodies, from where they pass into plants and animals, eventually entering the human body, i.e., the so-called migration of radionuclides (fission products) occurs. The fission fragments that contaminate the Earth's surface not only increase the natural background but also differ in nature from the isotopes that create natural radiation. Currently, Sr-90 and Cs-137 have been found in the air, atmospheric precipitation, soil, water, many plants (including those used for human food), muscles, bones, and other organs of animals and humans. It has been established that Sr-90 is most similar in properties to calcium and is localized in bone tissue.

The somatic effect of fission products depends on their nature, the degree and duration of radioactive exposure, as well as the individual characteristics of the organism. A dose of 400 R (Roentgen) is considered lethal for 50% of irradiated individuals.

The localization of radioactive substances in the soil depends on the soil composition, groundwater level, vegetation type, etc. For example, soils poor in calcium salts may contain large amounts of Sr-90. The amount of Cs-137 retained in the soil is probably related to the content of humic acids, which form corresponding complex compounds with Cs.

The amount of deposited radioactive products depends on the geographical latitude of the regions. For example, in the northern hemisphere (between 30° and 50° north latitude), it is about 3-4 times greater than in the southern hemisphere. The entry of long-lived fission products into the human body depends on the type of consumed food and is a result of the migration of radionuclides. For example, people who primarily consume plant-based food receive relatively more Sr-90 than those whose main source of food is milk and dairy products. The uneven contamination of the Earth's surface complicates the assessment of the consequences of nuclear weapon tests. Experimental verification of the impact of low doses of ionizing radiation created by global deposits is difficult, as observations must be conducted over many years and must ensure the statistical reliability of the results.

Observations on the consequences of nuclear weapon tests have always pursued a number of tasks, such as:

- Studying the formation and spread of radioactive aerosols in the atmosphere.
- Clarifying the patterns of radioactive fallout on the Earth's surface.
- Determining the content (degree of contamination) of artificial radioactive isotopes in various external environmental objects.
- Studying the distribution and migration paths of radioactive substances (natural and artificial) in the biosphere.
- Determining the impact of fission products on plants, animal organisms, humans, and the entire global population.

Solving these tasks requires the application of many scientific disciplines - nuclear physics, radiochemistry, hydrochemistry, biology, medicine, meteorology, oceanology, and soil science.

Studying global deposits, characterized by low concentrations of radioactive substances, requires the use of very precise research methods. Radiochemical analysis is performed using precipitation extraction, chromatographic, and other methods. Recently, devices for complete gamma spectrometric analysis, multi-channel gamma spectrometers, and for alpha - and less frequently beta-active preparations - thick-layer photo emulsions - have been widely used to determine gamma-emitting isotopes. Low-background 4 π counters and special alpha - counting chambers are used to measure radioactivity.

The aim of the study is to investigate Nuclear weapons - consequences for the biosphere in case of their potential use.

II. MATERIALS AND METHODS

Research methods:

- Theoretical methods.
- Mathematical statistical method.

The research results are presented in the work using tables and text [3].

III. RESULTS AND DISCUSSION

We distinguish between air, underground, and underwater nuclear explosions.

An air nuclear explosion is distinguished from other types by the fact that the luminous ball does not touch the Earth's surface. A cloud of dust and smoke forms at the site of the explosion, which rises after the spherical explosion cloud. The dust cloud generally does not merge with the radioactive cloud. In this type of explosion, the shock wave has the widest range of action, and light radiation can cause serious damage at great distances from the epicentre. The radioactive products formed in the explosion remain in the troposphere and stratosphere. The radioactive fallout on the ground in the first minutes, hours, and days creates a critical radiological situation mainly in the destruction zone and along the path of the radioactive cloud, but it is less severe than the situation that can be created by surface explosions.

A surface nuclear explosion occurs directly on the Earth's surface or at a height of several tens of meters above it. The fireball is shaped like a hemisphere or a truncated sphere lying on its base on the Earth's surface. In the area of contact between the fireball and the Earth's surface, the soil layer is crushed, melted, partially turned into vapor, evaporates, and mixes with radioactive products under the influence of high pressure and temperature. The molten soil turns into a glass-like, highly radioactive slag that covers the Earth's surface in the explosion zone after solidification.

Unlike an air nuclear explosion, a surface explosion generates a strong air flow, which forms a significantly larger dust cloud. This creates conditions for intense radioactive contamination of the area, both in the explosion zone and along the path of the radioactive cloud. In this

case, the shock wave and light radiation have a smaller range of action compared to the air explosion. The effect of penetrating radiation in surface and air nuclear explosions is similar.

The damage inflicted on agricultural crops in the Hiroshima and Nagasaki areas in 1945 by the use of nuclear weapons confirmed that vineyards and orchards, as well as their support structures, were the most sensitive to damage. The damage to orchards and their support structures was greater in areas that were positioned perpendicular to the direction of the shock wave. At a pressure of -0.3 kg/cm^2 , 30% of the trees are destroyed; at a pressure of 0.3 to 0.5 kg/cm^2 , 50% are destroyed; and at a pressure above 0.5 kg/cm^2 , the damage is complete.

The degree of damage to different crops varies depending on the distance from the explosion's center or epicenter, the plant's phenological stage of development, the variety composition, the development and power of the root system, and other factors. The orientation of the rows of perennial crops relative to the propagation of the shock wave is also significant [4].

In cereal crops, at early phenological stages of development, the plants may lodge but subsequently recover, without significantly affecting yields. At later phenological stages (milk-wax and full maturity), the damage may cause plant breakage, resulting in improper grain filling or partial shedding of mature seeds, thereby reducing yields.

Significant losses from the shock wave's impact will occur in vegetable crops, particularly tomatoes when the fruits have formed. Losses will be substantial at technical maturity. There will also be noticeable losses in sunflowers, corn, and some crops at later stages of development.

Protection of Plants from the Shock Wave: Considering the damage from the shock wave on cultivated vegetation, it can be noted that its spatial nature is limited (a few kilometres), and for the current level of agricultural production development, the shock wave does not pose a significant danger.

Protection of Plants from the Shock Wave: Considering the damage from the shock wave on cultivated vegetation, it can be noted that its spatial nature is limited (a few kilometres), and for the current level of agricultural production development, the shock wave does not pose a significant danger:

- Cereal Crops - Growing short-stemmed, lodging-resistant varieties; using the retardant CCC (chlorocholine chloride) to increase stem strength, applying good and timely agro-support (fertilization, irrigation, herbicide treatment), including avoiding separate harvesting, which is known to reduce the degree of loss; creating good organization in harvesting considering the extreme situation that has arisen.

- Perennial Crops - For the espalier formations of fruit crops and high formations of vines, special attention needs to be paid to the type and method of constructing the wire structures. The preserved products, if they cannot be used for fresh consumption, can be processed into compotes, grape juice, wine, or other concentrated alcoholic beverages.

As the shock wave moves, it carries various mechanical impurities, which settle on nearby territories and cause varying degrees of contamination of cultivated fields, meadows, and pastures. These areas need mechanical cleaning through sprinkling using different types of sprinkling equipment. Bees, plant pollinators, pollinate flowering plants treated with pesticides [5] - [8], contaminate honey with pesticides and may also transfer deposited radioactive elements.

The shock wave can cause the complete destruction of forest massifs at a front pressure greater than 0.5 kg/cm^2 . At this pressure, trees are uprooted, broken, and thrown aside, forming dense pile-ups. At a pressure of 0.3 to 0.5 kg/cm^2 , about 50% of the trees are destroyed, and at up to 0.3 kg/cm^2 —30% of the massifs. Young trees are more resistant to the effect of the air shock wave than older ones.

A. Light radiation

Among the destructive factors of a nuclear explosion, light radiation occurs the fastest. About 30% of the explosion's energy is used to form it. The source of radiation is the unreacted parts of the nuclear munition (charge, body, etc.) that instantly vaporize in the surrounding air, which heats up to several million degrees. Light radiation travels in a straight line at the speed of light. During a nuclear explosion, the duration of the glow is a few seconds, and in a thermonuclear explosion, several tens of seconds. For example, for a nuclear munition with a TNT equivalent of 1 km, the light radiation duration is 0.8 seconds, and for a thermonuclear explosion, it is 16 seconds.

When the temperature of the fireball's surface is 6000°C , the spectral composition of the light radiation is as follows: [4]

- Ultraviolet radiation with energy 13%
- Visible light with energy 31%
- Infrared rays with energy 56% of the total radiation energy.

Ultraviolet rays act immediately after the explosion and have harmful biological effects on living organisms, damaging human vision. Infrared rays have a thermal effect and cause the most significant damage to living organisms by causing various degrees of burns and igniting different objects, structures, products, and other unprotected objects.

The primary indicator characterizing light radiation is the light impulse, which represents the amount of light energy that falls on a unit of stationary and unshielded surface (1 cm^2), located perpendicular to the direction of the radiation spread throughout the glowing time. It is measured in joules per square meter (J/m^2).

The destructive effect of light radiation is expressed in its thermal effect on plants and objects. The light energy absorbed by plants and objects is converted into heat, heating them to varying degrees. The heating depends primarily on the amount of energy absorbed during illumination and other conditions, such as colour, shape, size, position of the heated surface, heat capacity, thermal conductivity, and the temperature of plants and objects at the time of heating.

The influence of colour is such that light-coloured plants reflect a significant portion of the light rays. Light colour hinders rapid and intense heating, while dark-coloured plants absorb most of the light and heat more intensely. Regardless of colour, in most agricultural crops, the strength of light damage will depend largely on the phenological stage of the crop. For example, cereal crops—wheat, barley, rye, oats, etc., during ripening, cease photosynthesis and turn straw-yellow. Naturally, they are expected to be most resistant to light radiation at this stage. In practice, the opposite is true. Semi-dried plants are most vulnerable to light radiation effects.

The shape of plant leaves and fruits also matters. Plants with wider, slightly convex leaves, arranged horizontally or downward-facing, such as most vegetable crops, potatoes, sunflowers, cotton, sugar and fodder beets, pumpkins, watermelons, melons, etc., will be more affected as light rays cover a significant portion of the leaf surface. Plants with vertically upright, elongated, and pointed leaves, arranged at various angles to the horizontal cross-section of the stem and at a sharp angle to the vertical cross-section of the stem, will be less affected. In round fruits, such as apples, pears, watermelons, tomatoes, etc., the light rays will cover and damage more than half of their surface. This phenomenon is often observed in practice, especially in tomatoes grown in cultivation facilities. Under the influence of sunlight, even though the light and heat impulse reaching the ground is reduced thousands of times, in summer, on a clear and warm day, sunscalds form on exposed fruits within hours, deforming or killing them. Essentially, sunscalds are identical to burns caused by light radiation from a nuclear explosion since the sun is a specific thermonuclear reactor where a continuous chain reaction occurs, synthesizing potassium nuclei from hydrogen nuclei.

The thickness of stems and leaves also affects the degree of light damage. In the case of a short-term heat impulse, as in a nuclear explosion, plants with thicker stems and leaves will absorb more energy than thinner ones. Therefore, damage to plants with thicker leaves and stems will be greater. An example of this is again the sunscald on tomatoes. While the fruits have large, pronounced burns, the leaves, under the same sunlight, exhibit minor burns.

The light flux of an air atomic explosion falls vertically on the surface in the nearby zone within a radius of 300-400 m. As the distance from the explosion centre increases, the angle of the rays changes. Thus, different crop types, depending on habitus, type of planting, and row direction, will be affected by light radiation to varying degrees.[9] Plants in the nearby zone, where the rays fall vertically,

regardless of habitus, planting type, and row direction, will be completely destroyed. As the distance from the explosion centre increases, the angle at which the rays fall becomes sharper. In this situation, in the distant zone, the light flux's effect will be greater on plants standing vertically or high above the soil surface (light radiation covers a larger plant surface). Orchards, vineyards, and field crops like corn, sunflower, cereals, etc., will be more affected than crops at the same distance from the explosion centre, like sugar beets, fodder beets, beans, peas, potatoes, etc. The propagation of light radiation at an angle allows for penetration and damage within the plantation. In this case, the planting type and row direction influence the degree of damage. Crops sown or planted at greater row spacing will be more affected by light radiation due to less shading. Conversely, densely planted crops have much more shading, providing natural self-protection (shielding). This also applies to row direction and row width. Crops with rows oriented towards the explosion centre will be more affected than those with rows arranged transversely. This explains the requirements for row orientation and direction when establishing new orchards and vineyards. In all cases where terrain configuration and prevailing winds do not interfere, rows are oriented north-south for optimal sunlight exposure.

The degree of light damage will also depend on terrain configuration. Crops and plantations in ravines, behind natural elevations, windbreaks, tall trees, and other obstacles crossing the light radiation rays will be naturally protected from its effect.

Meteorological conditions will influence the degree of light radiation. The more transparent the atmosphere, the further the light flux spreads. For example, the light impulse of a medium-calibre nuclear munition in good visibility at 1 km from the explosion site is about 30 (1 cal = 4.186 J). At the same distance, the light impulse in poor visibility is about 15 cal/cm², and in dense fog—515 cal/cm². In dense fog, light radiation decreases sixfold. In connection with the temperature of plants at the moment of light radiation, the time of day during which the nuclear explosion occurs affects the degree of damage. Damage will always be smaller at night and in the early morning hours.

TABLE 1 – PLANT DAMAGE AT DIFFERENT TYPES AND POWER OF EXPLOSION (IN KM)

Nature of the defeat	Blast Power			
	1 Mt		10 Mt	
	Air	Earth	Air	Earth
Grade Ist - wilting (<i>Slight heat damage on plants</i>)	20	13	53	34
Grade IInd - partial burn (<i>Significant heat damage to plants</i>)	14,5	9	40	24
Grade IIIth - General Burning (<i>Burning of cereals, orchards and forests</i>)	13	6	24	14

In a surface atomic explosion, the radius of damage is much smaller because the light flux travels parallel to the Earth's surface. Along its path, in this type of explosion, the

light rays encounter many more obstacles compared to an air explosion. Additionally, a significant portion of the light energy is used to melt the soil around the explosion centre, heat the ground-level air layer, and the dust raised by the shock wave. The damage caused by light radiation is of two types: direct and indirect. Direct action occurs when the light flux directly affects plants, causing overheating (scorching) or premature ripening of cereal crops. Indirect action occurs when light radiation affects plants through heated air masses caused by the fireball and fires ignited by agricultural products or vegetation. [4]

B. Penetration radiation

As a result of the nuclear or thermonuclear reaction, a very powerful stream of gamma rays, alpha and beta particles, and neutrons is generated.

Penetrating radiation includes ONLY gamma rays and neutron streams because alpha and beta particles have low penetrating ability in air. About 10-15% of the explosion's energy is used to form penetrating radiation.

The radius of penetrating radiation in an air explosion with a power of 20 Kt can be distributed as follows: up to 300 m - 100% mortality in exposed people (dose 10,000 R - Roentgen); up to 1.2 km - 75% mortality (dose 1,000 R); up to 2 km - radiation sickness of the 1st degree (dose 500 R).

In a thermonuclear explosion, lethal damage can occur at a distance of 3-4 km from the explosion's epicentre. The main source of gamma radiation is the "fragments" of substances from the atomic explosion, found in the fireball and the radioactive cloud. The effect of gamma rays lasts 10-15 seconds.

The destructive effect of penetrating radiation is determined by the ability of gamma rays and neutrons to ionize the molecules of living tissues, resulting in stable radioactive isotopes. These, in turn, decay, emitting alpha and beta particles and gamma rays. Thus, under the influence of neutrons, induced or secondary radioactivity arises. The elements formed in soil and water with the highest secondary radioactivity include zinc, iron, manganese, aluminium, sodium, etc. Secondary radioactivity is also acquired by food products, fodder, organs, and tissues of living organisms, were radioactive isotopes of sodium, phosphorus, chlorine, potassium, etc., form. [10]

Penetrating radiation and secondary radioactivity can have harmful biological effects on living organisms. Under these factors, agricultural crops will be irradiated, disrupting their normal development or completely killing them.

The most sensitive to radiation are those parts of the plants whose cells are in the process of division at the moment of irradiation and through which the plants form new cells and grow (root tips, leaf tips, fruits, etc.). It has been established that the inhibition of cell division depends on the phase in which the division occurs. In the early

phase, inhibition becomes an irreversible process, killing the cells and later the plant.

The unit of measurement for radioactivity in the International System of Units is the becquerel, named in honour of Henri Becquerel, with the designation Bq and dimension 1/s. One becquerel is defined as one transformation (or decay) per second.

When plants are exposed to lethal doses of radiation (LD100), they do not die immediately, but after 3 to 4 weeks as a result of damage to the plant's reproductive capacity. The most characteristic feature of irradiated plants is the absence of external symptoms by which the affected plants can be identified (turgor state and green colour of plants do not differ from the control). In irradiated plants, growth is halted. The plants remain "living specimens," not forming new leaves and branches. This is particularly characteristic of cereal crops affected at the tillering phase. In some cases, minimal growth is observed, due to cell elongation rather than division. In irradiated plants, meristematic tissue cells are mainly affected.

Sudden death of irradiated plants can occur, primarily near the explosion's epicentre within a radius of up to 500 m, where ultra-high doses are received. Thus, in wheat, death occurs immediately at 2,000,000 R, and in potatoes at 200,000 R. At small doses, radiostimulation is observed. Seeds of different plants vary in sensitivity to ionizing radiation, and accordingly, they are classified as radiosensitive—beans, corn, timothy, ryegrass, rye, wheat, etc.; moderately sensitive—peas, vetch, oats, barley, sunflower, etc.; and relatively resistant—peas, hemp, alfalfa, clover, tobacco, etc. Unlike vegetating plants, the resistance of seeds to radiation is several times higher and is directly proportional to their maturity level and storage duration.

When radiosensitive seeds are irradiated with a dose of 20,000 R, germination is hampered and growth is significantly reduced. In moderately sensitive seeds, this effect is observed at a dose of 90,000 - 100,000 R, and in relatively resistant seeds, the dose must be increased to 150,000 - 200,000 R [4].

In plants derived from seeds irradiated with high doses, morphological changes are observed—reduced height, shortened internodes and branches, thickened stem, reduced number and size of leaves. Slight colour changes are also noted—increased sterility and reduced yield. The shape of seeds obtained from irradiated plants does not change.

Depending on the radiation dose, various deformations occur, which can lead to malformations or valuable radiomorphoses—fasciations.

Unlike warm-blooded organisms, plants exhibit significantly higher radioresistance. In vegetating plants, the lethal dose varies within sensitive limits, allowing for the classification of three groups of plants based on their radiosensitivity. The first group includes those with an LD100 between 1,000 and 5,000 R—onion (kaba) 1,500 R,

oats 3,300 R, barley, rye, and wheat 4,500 R, corn 4,200 R, legumes about 5,000 R, peas 4,600 R, etc. The second group, with an LD100 of 5,000 to 10,000 R, includes apples and pears with radioresistance of 5,000 to 7,000 R, plums and peaches 6,000 to 10,000 R, onions and garlic 7,000 to 10,000 R. The third group, with an LD100 above 10,000 R, includes the following crops: cabbage with radioresistance of 12,300 R, tomatoes 12,400 R, eggplant 15,000 R, potatoes 12,600 R, sunflower 20,000 R, rice 19,600 R, flax and hemp 20,700 R, and others.

The radiosensitivity of plants will be influenced by cultivation techniques, the physiological state of the plants, and climatic factors.

The effect of ionizing radiation is also influenced by external environmental conditions. At low temperatures, the radiosensitivity of plants increases. When cooling occurs during the vegetation period, damage to irradiated plants increases. Precipitation (atmospheric and soil moisture) plays a certain role in the effect of radiation, with high moisture levels increasing the radiosensitivity of plants. However, it should not be forgotten that this is related to the plant's phenological phase of development. The gas environment (atmosphere) has a significant influence, primarily depending on the oxygen content. The so-called oxygen effect of radiation is manifested. With increased oxygen content in the atmosphere, the radioresistance of plants increases. The presence of carbon dioxide (CO₂), hydrogen (H), and other elements inhibits the effect of ionizing radiation.

Abundant and prolonged illumination reduces the impact of ionizing radiation on plants. This shows that in determining the biological effects of radiation on plant organisms, all factors influencing its effect must be considered.

In the primary processes occurring in cells under the influence of radiation, ionization and related chemical changes play a key role in the observed biological effect. Under the influence of ionizing radiation, positive and negative ions from the molecules of the chemical components of the cell are formed in the building blocks and other constituents of the cell [10].

The predominant component of the living cell is water, which accounts for the highest percentage of interaction between its molecules and radiant energy. Two types of ions are formed—positive and negative. [11, 12, 13]



The ejected electron attaches to another electrically neutral water molecule, converting it into a negative ion:



The resulting ions have an unstable electron structure, quickly dissociating to form two free radicals - hydrogen (H⁺) and hydroxyl (OH⁻), and two stable ions (H⁺ and OH⁻) that recombine to form water molecules:



The resulting free radicals also undergo recombination, forming water, molecular hydrogen, or hydrogen peroxide:



In the presence of oxygen in the environment where ionization occurs, other reactions are also possible:



These recombination reactions occur in the presence of oxygen and form the basis of the oxygen effect of radiation.

Similar changes are observed in the molecules of other chemical components of the cell—proteins, carbohydrates, fats, etc. The formation of free radicals completes the primary impact of ionizing radiation. Subsequently, secondary processes occur in which free radicals, produced by the radiolysis of water, react with the substances dissolved in it. This highlights the important role of water as a material (transport) carrier of ionizing radiation. Modern theory of radiation damage to organisms is primarily based on the radiolysis of water (the property of radioactive radiation to ionize substances being its most characteristic feature). [10]

Supporting this claim is the rule that the radioresistance of biological objects increases with the decrease in relative water content. Ionizing radiation does not directly affect the bio-object but indirectly through the radiolysis of water.

It is assumed that chain reactions occur in cells after irradiation, indicating that ionization does not diminish but proceeds with varying intensity along the biological chain.

Under the influence of direct radiation and the products of water radiolysis, biologically important molecules of the cell's main components are irreversibly altered.

Changes also occur in nucleic acids (protein components of complex proteins—nucleoproteins), which contain ribose—ribonucleic acids (RNA), and those with a carbohydrate component—deoxyribonucleic acids (DNA). Changes in them under the influence of ionizing radiation are crucial (DNA is the material carrier of heredity). Usually, the negative biological effect is expressed through two groups of reactions:

- The first affects the genetic code;
- The second destroys the carbohydrate part (matrix) of DNA.

These changes usually lead to strong genetic mutations. Carbohydrates, which are biochemically active cell compounds (monosaccharides, disaccharides, and polysaccharides) and are an important energy source for cell and organism building blocks, undergo changes in the concentration of sugars in glucose and fructose solutions under the action of ionizing radiation. Fructose decreases, acidity increases, and formaldehyde and molecule

destruction appear in the solution, leading to their degradation. [10]

IV. CONCLUSIONS

In our opinion, these issues deserve special attention from both scientists and specialists involved in nuclear, chemical, biological, and environmental protection in the state management system, at the national, regional, and municipal levels, defence, and national security, as well as the activities of supervisory and control authorities in this regard.

Theoretical research and the development of necessary and effective practical measures in these areas conducted so far represent a significant contribution to improving and developing such important interdisciplinary fields of scientific knowledge and practical spheres, such as radiation, chemical protection, and environmental security. Nonetheless, it is undeniable that much more needs to be done in this regard.

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