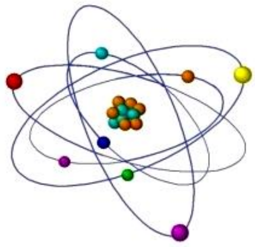
"LOW" DOSES OF RADIOBIOLOGY



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ABSTRACT: *The main radiobiological problems in the example of the Chernobyl accident are considered. It is pointed out that nowadays there is a paradoxical inconsistency between the relevance of radiobiological problems in the post-Chernobyl period and "low doses" of efforts that are made by radiobiologists to solve them. It is substantiated that at this stage of the development of the post-accident situation the existing experimental facts and theoretical provisions of radiobiology are quite sufficient to explain radiobiological and radioecological phenomena. Special attention is paid to the problem of "low" doses of ionizing radiation. The existence of "hot" particles of biological origin is experimentally proved. Special attention is paid to the inter-granular reactions of biological systems to irradiation in the example of gigantism of tree needles in the zone of the Chernobyl accident influence. The data on rating assessment of the degree of urgency of radioecology problems are presented. The role of radiophobia in psychosomatic diseases of the population in the zone of strict radiation control is considered.*

Key words: low dose, radionuclide, radiohormesis, radioadaptation, radiomodification.

INTRODUCTION

While during the Chernobyl era the staff of the Department of Biophysics and Radiobiology of the Institute of Plant Physiology of the Academy of Sciences of Ukraine had to deal mainly with the issues of "acute" radiobiology, studying deterministic effects of ionizing radiation (IR) in plants, after the Chernobyl accident the research focus changed sharply to the area of "dumb" radiobiology – studying the effects of low-dose and low-power ionizing radiation. Right now, on the eve of the 39th anniversary of the Chernobyl accident, the relevance of a number of practical and conceptual problems, the solution of which will allow us to "weigh" rationally the risks for human beings from all kinds of environmental stressors, is realized quite acutely. These are, first of all, the problem of the effect of acute IR doses on humans and, first of all, the consideration of the phenomenology and mechanisms of ARS, and, secondly, the complex of "Chernobyl problems". The relevance of the latter topic (scientific, economic, political, moral) is undoubted and gives a reason to consider the results of the effect of the so-called "low" radiation doses to which the population is exposed due to the Chernobyl accident. Nowadays there is a paradoxical discrepancy between the relevance of radiobiological problems in the post-Chernobyl period and "low doses" of efforts that are made by radiobiologists to solve them. It is necessary to bring all this into conformity, if only for the reason that more than 3 trillion US dollars have already been spent on radiation protection in the world, while in Ukraine in the post-Chernobyl period about 12% of the annual budget has been spent on liquidation of real and imaginary consequences of the accident. For this reason, radiobiology can be considered the most important biological science for Ukraine, as its development will significantly reduce the costs of "consequence management", based, in particular, on a more accurate assessment of radiogenic risk coefficients, which, in turn, will eliminate many scientific medical units parasitizing on the Chernobyl issue.

Let us consider the main radiobiological problems in the example of the Chernobyl accident. It is obvious that the Chernobyl accident could not have been overlooked by numerous radiobiological and radiological disciplines. The avalanche of publications generated by this interest makes us think about the emergence of a fundamentally new factual field, which requires additional research efforts on the part of radiobiological specialists. But is it really so? Did the accident at the Chernobyl NPP entail any really unique (new or unusual) phenomena and processes from the radiobiological and radiological points of view, distinguishing them from the previously known phenomena? From our point of view, it is possible to speak about the uniqueness of the accident only with regard to its "technical" characteristics, mainly concerning the nature of radionuclide contamination of natural and man-made objects.

RANGE OF RADIOBIOLOGICAL PROBLEMS

In our opinion, at this stage of post-accident development, the existing experimental facts and theoretical concepts of radiobiology are sufficient to explain radiobiological and radioecological phenomena. Nevertheless, the Chernobyl accident caused essential changes in radiobiological science. This situation actually "saved" radiobiology, if not from "extinction", then from a significant reduction in funding.

If the totality of radiobiological problems is represented as a problem spectrum with its qualitative (many problem areas) and quantitative (human, financial, material and time resources spent on solving a particular problem) characteristics, it can be stated that in the post-accident period it has undergone only quantitative changes. In fact, there has been only a shift of research accents to the area of problems previously little studied and researched, for example, such as problems of radio-adaptation, radiation aging of organisms, aging of radionuclides, radiation-induced carcinogenesis and others. Insufficiently studied and developed remain in particular the following issues:

1. *Heterogeneity* (*tropicity*) of radionuclide (RN) distribution in plant structures and organs. Necessity to study ***"hot" particles of*** biological origin, the existence of which is indicated by the results of studies of radionuclide distribution on root structures in soil and water habitats of plants.
2. *Specificity of* action of incorporated radionuclides. There is an opinion that incorporated radionuclides in biological objects have an increased damaging effectivity. We believe that if the distribution of radionuclides in the biostructures under study is determined correctly (taking into account the tropism of distribution, starting with the intracellular level and ending at the community level), the specificity of such a specificity is absent. In fact, there is no reason to speak about a particularly high damaging effect of IR doses formed by incorporated sources.
3. Effects of "*low*" *doses of* IR. Firstly, "small" doses turn out to be not small at all (see point 2), and, secondly, considering "small doses" as subthreshold doses, any attempts to "demonize" them are excluded.
4. Phenomenology, mechanisms and significance (on-togenetic and phylogenetic) of *radiohormesis effects*, which are based on hyper-compensation of radiation-induced damage to biological structures of different levels of integration – from macromolecules to cenoses; in this state the object acquires increased resistance to subsequent stressing influences for a certain period of time.
5. The problem of *radioadaptation*, starting with phenomenology and ending with ontogenetic and phylogenetic mechanisms. Radioadaptation is based on the hormesis effect of IR (see point 4); radioadaptation should be considered not only as an increase in the initial level of radioresistance (hyperadaptation, "adaptive response"), but also as its decrease (hypo-radioadaptation) to a level still compatible with life activity; the necessity to take into account the phenomenon of *reverse* adaptation, when adaptive doses can act as radiotherapeutic doses, has been experimentally substantiated.
6. *Microevolutionary* processes in the 30-km zone of the Chernobyl NPP induced by IR. Most often there is no clear dosimetric "support" for this kind of research and the endogenous rhythm of values of biological parameters, for example, virulence or pathogenicity of microorganisms, is underestimated, that leads to radio-centrism in explaining the observed phenomena.
7. Effects of *combined* influence of IR with other stressors. There is no practice of using the methods of calculating non-additivity, for example, the methods of mathematical planning of experiment are insufficiently used; mistakenly all the effects of combined influences are assumed to be negative and synergistic.
8. Methods of *retrodosimetry.* Insufficient attention to the possibilities of biodesimetry; lack of development of equidosimetric approach as one of the bases of retrodosimetry.
9. The usage of *radiation sensitized* biological objects as test systems for controlling the level

of radiochemical, chemical and biological contamination of various artificial (man-made) and natural environments (the techniques are based on synergistic effects – see point 7).

9. *Integral* (remote, mediated, indirect) reactions of biological systems to irradiation. The dominance of unfounded ideas about the decisive role of direct IR action; reduction of indirect IR effects to the "witness effect"; underestimation of the modifying influence of biological structures of any level of integration.

10. *Epigenetic* effects of IR. There is a peculiar genocentrism in explaining the effects of IR, or the other extreme issue – explaining the effects of IR only on the basis of molecular mechanisms of gene activity regulation and underestimating the supracellular mechanisms, for example, the effects of positional information, correlative links of biostructures at different structural and functional levels.

11. Excessive attention to *deterministic* effects of IR in the period after the Chernobyl accident without sufficient "dosimetric" grounds, i.e. an attempt to study deterministic effects in the radiation environment (at doses and power of IR in a specific post-accident situation), in which they cannot manifest themselves in principle.

12. *Stochastic effects of* IR. Paradoxically, little attention is paid to the assessment of carcinogenic radiogenic risks (the levels of which, in our opinion, are overestimated by two orders of magnitude to assess the consequences of exposure) at the background of hyperdiagnosis and lack of proper statistics; experimentally unjustified adherence to the threshold-free concept of IR action.

13. *Fundamental radiobiological laws.* Excessive attention of academic institutes to applied aspects of IR, turning them into branch institutes.

14. ***Radiobiology as a methodological basis for*** theoretical stress-biology. The necessity to use methodical and methodological achievements of radiobiology and radioecology to develop general principles of stress-biology and theoretical biology.

PECULIARITIES OF RADIONUCLIDE CONTAMINATION

The uneven character of RN distribution in the territories adjacent to the accident zone (horizontal "spotting"), caused by fractionation of RN at the stage of their release from the destroyed reactor, the presence of vertical heterogeneity of RN distribution in the soil and the presence of "hot" particles in the habitat of plants and animals led to the fact that living organisms in the radionuclide contamination zone began to be exposed to the action of radiation sources of very heterogeneous composition and distribution. However, taking into account the fact that the actual radiobiological stage of interaction of a radiation factor with a biosystem starts with the moment of penetration of RN into the organism or with the moment of the beginning of a significant effect of external irradiation, the "prehistory" of RN migration at this stage is not important for the assessment of the radiobiological effect, being reflected only in the kinetics of the external irradiation effect or in the parameters of RN intake into the organism. At the same time, the power of radiation exposure and the character of RN distribution in tissues may change (a consequence of differential RN tropism), but from the "point of view" of dosimetry, it does not create new situations of interaction between radiation sources and biological objects and, consequently, cannot cause a qualitatively new radiobiological phenomenology.

THE PROBLEM OF "LOW" DOSES OF IONIZING RADIATION. "HOT" PARTICLES OF BIOLOGICAL ORIGIN

The most striking example of the "shift" of radiobiologists' research emphasis in the post-Chernobyl period is the increased attention to the problem of "low" IR doses. The radio-ecological situation created after the Chernobyl accident caused such characteristics of dose loads on organisms, which forced radiobiologists to proceed to a close study of the so-called "low" IR doses associated, as a rule, with conditions of chronic irradiation and causing mainly stochastic effects (mutagenic, carcinogenic, genetic).

In the radiobiological literature there is no consensus on the content of this concept [1, 2]. Probably, the most practical definition of “low” doses would be to define them as poorly studied due to many methodological and methodological difficulties (difficulties of dosimetry, statistical processing of data, necessity to conduct large volumes of studies, the complexity of interpretation of the results obtained). It is obvious that most of the reactions under study have a certain threshold of sensitivity and/or resistance to irradiation. This applies, first of all, to deterministic effects. It is obvious that the only threshold-free reaction will be ionization and excitation of atoms and molecules of the irradiated object, since the energy of quanta or particles of the IR far exceeds the ionization energy of atoms or the energy of covalent bonds in molecules. In this connection, the issue about the threshold effect of radiation at the molecular level is removed and it is simply incorrect to speak about “small” doses with regard to these reactions. In fact, any absorbed dose of IR is capable of inducing a response at the molecular level, and the whole problem comes down to its detection.

There is experimental evidence that *stochastic effects* also *have dose thresholds.* Thus, the possibility of increasing the absorbed dose from background values, i.e. from the level of RB (radiation background), to a level that does not increase the background frequency of cytogenetic damage has been shown. The exceeding of this dose level leads to the emergence of a “*radio-adaptive response*”, when a lower (compared to background) frequency of cytogenetic damage is observed. Further dose increase leads to an increase in the yield of cytogenetic damages [3]. In this case, the concept of "subthreshold doses" includes the range of adaptive doses.

All reactions (stages of reaction) to irradiation develop within a specific structural and functional hierarchy of the studied biological system (potentially from the cell level to the level of ecosystems and the entire Biosphere). If reactions have a pronounced threshold character, the dose dependence has a true shoulder. Only for such reactions it is reasonable to speak about the existence of “small” doses, which are more correctly (more strictly and understandably) called subthreshold doses.

Of course, a subthreshold dose for one type of effect may simultaneously be above-threshold for another effect and vice versa. For example, subthreshold doses for insects with the respect to the effect of irradiation on their average life expectancy appear to sterilize or at least disrupt gametogenesis. In another situation, a subthreshold dose with respect to the inhibition of a function may turn out to be a suprathreshold dose with respect to the hormesis effect on the same or another function. In other words, we should speak about a complex potential structurization of any studied threshold, which, in general, has an area of indifferent influence (threshold proper) of irradiation and an area of radiation hormesis.

Thus, when studying the reactions of biological objects of any structural and functional level, one can always distinguish a range of doses called “small”, which are inherently subthreshold. Irrespective of the nature of the IR induced effect, i.e. whether it is stochastic or deterministic, from our point of view most of the doses absorbed by biological objects in the territories contaminated after the Chernobyl accident should be called “quasi-background doses”, by that emphasizing their proximity to the parameters of the natural radiation background (NRB). The problem of "low" doses has another important aspect, which reflects the effect of radionuclides predominantly incorporated in biological objects. It is about the existence of differential tropism of organelles, cells, tissues, etc. with respect to the accumulation of radionuclides. The calculation of doses from incorporated sources absorbed by biostructures without taking into account the heterogeneity of their endogenous distribution may give underestimated ratings and force researchers to make erroneous conclusions about the particularly high efficiency of low doses. In critical structures of biological objects there can occur rather high levels of RN accumulation (absorption coefficient up to 40000) and, consequently, high absorbed doses, which are commensurate with the corresponding doses of acute external irradiation of equal effectiveness. Such work was carried out by the author on plant seedlings, the results of which led to the necessity to conclude about the existence of “hot” particles of biological (in this case, plant) origin. This phenomenon was demonstrated in experiments with strontium-90 and cesium-137 salts. The observations were carried out on the roots of pea seedlings. Methodological details of this work are described in the monograph "Hyperadaptation. Stimulated ontogenetic adaptation of plants" [4].

Thus, the problem of low doses may be, on the one hand, a problem of not very strict scientific jargon, and, on the other hand, a problem caused by underestimation of the role of the heterogeneous tropism of radionuclides. The concept of “low” dose is actually a metaphor reflecting the aspiration of radiobiologists to study the reactions of the most fundamental structural and functional level of organization of biological systems. From this point of view, this concept with all its vagueness fulfills an important function of concentration of radiobiologists' research efforts around such important problems as induction of new and modification of constitutive repair systems, mechanisms of radiation mutagenesis and carcinogenesis, the problem of radioadaptation and others. In order to work effectively in this field, radiobiologists had to go into the area of such doses that do not cause non-mediated visible changes at the organism level. Otherwise, it would be impossible to study “low-level” effects because they are masked by cell lethality. This is probably the origin of the practice of using the term “low” doses. However, on the other hand, it should be noted that this concept has a negative effect for distribution of researching radiobiologists' accents, distracting their attention from solving equally important problems of radiobiological objects of higher levels of integration (organisms, populations, communities etc.).

In addition, it is important to note that the research focus of radiobiologists is distracted from solving equally important problems of radiobiology of objects of higher levels of integration (organisms, populations, communities, etc.).

RADIATION HORMESIS. RADIOADAPTATION PHENOMENON

Dose loads on biological objects in the zone of influence of the Chernobyl accident determine a variety of radiobiological effects, among which radiohormesis effects are of the greatest interest. The term “*hormesis*” (from Greek “hormesis” – “rapid movement, striving”) was introduced to denote the positive effect on biological objects of certain ("small") doses of factors of practically any nature – from physical to biological [5-7]. For example, it can be expressed in the increase of reproductive capacity, growth and development rate, resistance to biogenic and abiogenic factors (survivability), speed and quality of recovery processes, etc. In real habitat conditions, organisms are subjected to the stressing effect of factors of diverse nature. According to the Arndt-Schultz law, weak irritants (doses of factors) stimulate organisms' vital activity, medium irritants enhance it, strong irritants strenthen it, and very strong ones paralyze or even cause their death. In fact, this rule clearly indicates the existence of a hormesis dose range. If IR acts as a factor capable of producing a hormesis effect, in this case we speak of *radiohormesis*. Radiohormesis effects (RHE) are observed at all levels of biological integration and for representatives of all systematic groups of organisms. It seems possible to consider RHEs as a kind of stress reaction – eustress according to G. Sellier. It is obvious that the primary mechanism of action of radiohormesis doses (RHD) is based on ionization of atoms and molecules of the irradiated object, i.e., a disintegrative process, the fact of which makes RHE paradoxical – the primary destructive factor eventually exerts a beneficial (radiohormesis) effect.

The mechanism of hormesis effects can be explained from the standpoint of Weygert's law of supercompensation, according to which the organism in response to “waste of substances or loss of tissues” (within known limits) reacts by forming new substances and tissues in an amount *exceeding* the lost ones. In other words, in the recovery period after a load (of a particular dosage of the factor) there is a peculiar “exaltation phase” – the phase of supercompensation, the presence of which indicates such a state of the biological object, in which it acquires additional capabilities to respond to the action of the stressor, i.e. indicates a state of increased compared to the initial stability. If every time after the stress the organism returned only to the initial state, the possibility of acquiring increased stability would disappear.

Previously, we showed a direct connection between the state of hyperadaptation of plants to the action of IR and the state of radiohormesis in growth parameters, which gave us grounds to reduce the study of the mechanism of radioadaptation to the study of the mechanism of radiohormesis (Mikheev et al., 2007). One of the mechanisms of hormesis (and hence adaptation) by growth parameters turned out to be stimulation of histo- logical parameters of the root apical meristem (proliferative activity of meristematic cells, meristem volume, and cell size), which was preceded by stimulation of cytokinin activity in the meristematic zone of the root apex.

The fact of hierarchical organization of biosystems provides for the study of RHE mechanisms in the form of a sequential description of reactions of all sublevels (subsystems) of the biological object for which it is described. We tried to realize this methodological approach by the example of studying RHE in plants. We experimentally demonstrated the existence of a hierarchical system of radiohormesis mechanisms. The results obtained allow us to substantiate the hypothesis of the existence of supracellular mechanisms of radiohormesis detected at the organ level, which is based on the stimulation of cytokinin and, as a consequence, proliferative activity of cells forming critical plant tissues.

After exposure to an unfavorable factor (stressor), the organism can be in one of the following states for a certain period of time: a) at the initial level of adaptation, when its constitutive (current) level of adaptation is maintained – the state of *ordinary* adaptation; b) at the level of increased resistance, when the initial resistance of the object to the following effects of stressing factors increases – the state of *hyperadaptation* (eustress state according to G. Sellier); c) at the level of decreased resistance – the state of *hypoadaptation* (distress state according to G. Sellier). How can the degree of adaptability of an organism change? It is believed that the organism under the influence of a stressor undergoes a *transitional process*, which has a character of either incomplete recovery (under-recovery, *hypocompensation*) or over-recovery (*hypercompensation*) of structural-functional parameters characterizing the organism's vital capacity (growth and development rate, cell division rate, etc.). In fact, the transition to the state of hypercompensation is a consequence of inaccuracy *and inertia of biological* repair *systems* that function at all levels of integration of biological systems (enzymatic repair, cellular repopulation, regeneration, repopulation at the level of organism population).

RADIATION AND PHYLOGENY

It is not excluded that the increased attention to the problem of radionuclide concentration by certain biological structures will revive the interest in studying the role of the radiation factor in phylogenetic processes, which had died out. It is now becoming obvious that it is wrong to be guided only by averaged values of the natural radiation background in order to estimate dose loads on the organism. This is especially true for aquatic and soil organisms. Real dose loads may be significant enough for IR to act either as a factor of organismal variability, or as a selection factor, or both.

We would like to draw attention to some aspects of the problem “radiation and phylogeny”, which become especially relevant in the post-Chernobyl period, when the level of radiation background significantly increased.

Multilevel structure-functional organization of phylogenetic factors. Postulates: 1) phylogenetic factors can be of any nature, i.e. of any level of complexity; 2) in the process of progressive development, the phylogenetic factors are more and more organized factors, the action of which occurs against the background of the action of less organized factors.

Dosimetry of phylogenetic factors and their classification according to the produced effect. Indifferentiating, stimulating, inhibiting and lethal phylogenetic factors. Postulate: with progressive evolutionary development, the role of informational aspects of phylogenetic factors increases, while the role of energetic and material factors decreases.

Additivity, synergy and antagonism of phylogenetic factors. It is obvious that a complex of endogenous and exogenous phylogenetic factors has acted, is acting and will act on the developing systems that in the end forces us to solve the problem of studying the mechanism of their interaction. The lack of consideration of the need to solve this problem makes it impossible to obtain a reliable picture of phylogenetic transformations.

“Retrodosimetry” of phylogenetic factors, i.e., determination of qualitative and quantitative parameters of phylogenetic factors that *acted in the historical past.* Just as in radiobiology the “doza-effect” calibration curves obtained in an experiment are used for this purpose, a similar approach could be used to solve phylogenetic problems of retro- dosimetry. For this purpose, phylogeneticists need to establish a clear dependence between the parameters of a particular phylogenetic process and the doses of the phylogenetic factor. By the way, what is a phylogenetic factor in general? From our point of view, a phylogenetic factor is a factor of any nature (physical, chemical, biological), which acts in a series of

generations of a biological system and causes a persistent inheritance of its properties that have arisen due to interaction with this factor.

THE COMBINED EFFECT OF IONIZING RADIATION WITH OTHER FACTORS OF PHYSICAL, CHEMICAL AND BIOLOGICAL NATURE

The second major area of research, the attention to which increased in the post-accident period, was the study of the combined effect of IR with other environmental factors. The absence in the pre-accident period of a sufficient number of experimental and theoretical studies of the joint action of IR with factors of physical, chemical or biological nature led to the spread of the opinion that all possible types of interaction of environmental factors with IR are exclusively synergistic, i.e., reinforcing mutually negative influence of each other. At the same time, it is forgotten that, in general, factors can interact both additively and antagonistically, when they mutually reduce their negative effect, and synergism itself can be observed as a process of mutual strengthening of positively (hormesis) acting factors. In addition, attempts to study the combined effects are carried out without preliminary obtaining dose dependencies for individual factors, which would lead to the conclusion about the ambiguity of the influence (by sign) of factors on the object (process or structure) under study.

RADIOMODIFICATION PROBLEM

Ultimately, the problem of “synergism” is a particular case of the more general problem of modification of radiobiological reactions by a variety of factors acting before, during or after irradiation. From this point of view, the problems of protection against chronic exposure, radioadaptation, inducibility of repair systems, dose reconstruction, biodosimetry, etc. are aspects of either the problem of quasi-phonic (“low”) doses or the problem of synergism (modification). We would like to dwell especially on the last two problems, i.e. on the problem of dose reconstruction (the problem of retrodosimetry) and on the problem of biodosimetry. It seems to us that significant results in these areas can be achieved by using the methodology of modifying effects research. On the one hand, when it comes to retrodosimetry, by applying additional (“manifesting”) effects on the irradiated object, "hidden" radiation damage is revealed, or, more precisely, is transferred to a higher level. On the other hand, for the purposes of biodosimetry it would be advisable to use pre-sensitized objects, counting on the nonlinearity of interaction between sensitizing and radiation factors that will make the biodosimetric system more sensitive.

It is still important to consider one type of post- radiation positive modification of the effect of radiation factor in inhibitory doses. Positive post- radiation effects of incubation conditions (reduced temperature, “starvation environment”, etc.) are well known in radiobiology. In this case, the post-radiation factors create conditions for more efficient/effective work of intra- and supracellular repair systems. The peculiarity of our proposed approach is the idea of using IR by itself as a positively acting post-radiation factor. In other words, we tried to test the possibility to exert a “radiotherapeutic” effect (“treat”) on acutely irradiated objects by additional irradiation in the post- radiation period, i.e., to apply hormesis doses as "prophylactic" doses. In stress-biology, this possibility (in fact, radiation “homeopathy”) is not sufficiently studied. We have experimentally studied this type of modification, having called it "reverse adaptation", when as a therapeutic (“reversely adaptable”) influence, different impacts, including chronic IR, have been used for the therapeutic (“homeopathic”) effect on the plant object. The therapeutic (“homeopathic”) effect of post- radiation irradiation was observed in experiments with bean, evening primrose and pea seedlings. Probably post-radiation "radiotherapeutic" procedures modified the work of the recovery systems of irradiated plants, creating additional opportunities for more complete recovery at the intracellular (molecular) or cell-population levels. The results obtained are suggested to be considered as an experimental basis for the method of "low-dose radiotherapy" which may possibly find its application in the treatment of ARS.

INTEGRAL REACTIONS OF BIOLOGICAL SYSTEMS TO IRRADIATION

One of the radiobiological directions, the problems of which have acquired special urgency, is the study of integral (remote, mediated, indirect) reactions of biological systems to irradiation. Complexity, multilevel nature of biological systems, rapidity of functioning of their constituent elements and structures should inevitably be reflected in their radiobiological reactions. Most often the integrality of radiobiological reactions is manifested in the so-called remote (mediated, indirect) effects of irradiation. Let us illustrate the significance of integral reactions in the example of gigantism of needles observed after the Chernobyl accident at some sites in the Chernobyl Exclusion Zone.

The gigantism of needles and leaves observed in plants growing in some areas of the 30-km zone of Chernobyl NPP could be explained by considering it as a consequence of the direct effect of irradiation on needles [8]. However, strict adherence to the principles of system analysis, in particular, taking into account the necessity to describe the mechanism of the phenomenon at a specific structural-functional level, involving for this purpose information about the behavior or reactions of the elements directly forming this level, makes us look for another explanation of the gigantism of needles. From our point of view, irradiation at comparatively low (subthreshold) doses for differentiated cells (forming the bulk of photosynthetic tissue), but lethal for meristematic cells, led to massive but incomplete death of apical stem growth points. This led to the fact that a small number of surviving apices turned out to be acceptors of assimilation products, synthesized by the photosynthetic apparatus, which has a significantly higher level of radio resistance [9]. Thus, the limited number of stem apices (obesity meristems) and the needles laid in their structures were provided with an increased amount of nutrients, i.e., in fact, the effect of "fatness" of leaves and shoots well known in plant physiology, was observed. In other words, gigantism of needles was probably a consequence of the disturbance of correlative relationships in the irradiated plant. The validity of this explanation is confirmed by the data of N.I. Goltsova [10]. It turned out that complete or partial death of terminal and lateral buds led to an increase in the life span of the old, pre-accident needles of 1984–1985. Apparently, with the partial death of apical buds, apical dominance regulated by auxins and cytokinins decreased or completely disappeared, so that cytokinins transported upward from the root under the conditions of apical bud death stimulated the growth of the remaining adventive and dormant buds and had a juvenilizing effect on the already formed needles.

The removal of anthropogenic impacts (plowing, use of pesticides, mineral fertilizers, cattle grazing, etc.) leads to the recovery and even, in some cases, to the super-recovery of quantitative and qualitative parameters of populations, communities and cenoses. An illustration of this can be the fact of the super-recovery of wild boar numbers in the forests of Belarus, which were subjected to radio-nuclide contamination. In general, the 30-km zone of the Chernobyl NPP can serve as a huge reserve- polygon (paradoxical as it may sound) for studying succession processes.

Radiophobia and the *relief of anthropogenic pressure* (chronic and/or acute anthropogenic stress) on natural and artificial ecosystems are prime examples of radiation mediated effects. Even ardent supporters of the absolute threshold of radiation action do not take into account the possibility of radiation action mediated through the human psyche. In this case, people are affected not by IR itself, but by the fear of it, caused, on the one hand, by the lack of sufficient objective information about the degree of IR danger, and, on the other hand, by the availability of information about the real negative effect of IR in case of acute exposure, as it was in the case with the firefighters who put out the fire at the Chernobyl NPP.

DETERMINISTIC EFFECTS

We would not like to dwell in detail on deterministic effects in connection with the Chernobyl accident, as there is an extensive literature on this subject. We will only mention a few points. Firstly, the total number of the injured among the personnel working at the Chernobyl NPP on April 26, 1986, was 203 people, 115 persons among them were treated in a specialized hospital in Moscow from the second day and 19 persons in Kyiv. The subsequent change in the group size to 237 persons concerned only patients with acute radiation sickness (ARS) of the first degree (the mildest), who were treated in Kyiv. Isn't this where the myth about more effective treatment of ARS in Kyiv arose? Out of 499 hospitalized people, the diagnosis of ARS was confirmed in 134 people. According to official data, the number of people who died in different periods after irradiation from acute radiation sickness, aggravated by extensive thermal burns, amounted to 28 people. And, secondly, not a single case of chronic radiation sickness (CRS) has been registered for all the years after the Chernobyl accident. Let us now turn to the statistical data characterizing the natural mortality rate and compare them with the data on mortality among the liquidators [11]. There was no increased mortality among liquidators (for example, Robert Peter Gale, an American specialist in bone marrow transplantation, having arrived in Kyiv in June 1986, estimated the number of future fatalities at 80000) of 1990. On the contrary, mortality was naturally lower in all three republics compared to the controls, which included working-age men. Of course, there is still no reason to believe that there is a radiohormesis effect. Probably the most correct assumption at this stage would be that the effect is due to the selection of healthier men for the number of liquidators.

STOCHASTIC EFFECTS

What stochastic effects can cause "Chernobyl" ("small") radiation doses in humans? Our interest in this problem arose due to a paradoxical situation – an extreme discrepancy between the importance of radiation safety and regulation on the one hand, and the number of relevant studies conducted in the countries of the former Soviet Union. Radiobiology, first of all, "serves" human interests, and it is very strange that the ICRP recommendations will play the role of a "sacred cow" of standardization. In fact, we can speak about one more "basic" radiobiological paradox. The problem of assessing the risk of stochastic consequences (first of all, carcinogenic) of IR has two aspects. First, it is a pre-dosimetric subproblem (adequate assessment of the IR dose, its distribution over critical tissues and organs, etc.), and, second, it is a subproblem of assessing the type and kind of relationship between absorbed doses and the probability of stochastic effects. As far as a cursory analysis of the Russian literature allows, the efforts of radiobiologists of the post-Soviet space are mainly focused on the first aspect.

We made an attempt to estimate ("reassess") the carcinogenic radiogenic risk on the basis of data on spontaneous instability (thermodynamic, chemical) of DNA. However, let us first see how the carcinogenic risk coefficients recommended for use by the ICRP "work" in relation to the assessment of the Chernobyl accident consequences. Taking into account the value of the collective dose received by the inhabitants of the "affected" regions of Ukraine, Belarus and Russia (approximately 200,000 people according to the estimates of L. A. Ilyin and colleagues [12], and the ICRP proposed carcinogenic risk coefficient, the number of fatal cancers should be estimated at approximately 10000 (note, by the way, that the Chernobyl Forum estimates this value at 4000), which will be less than one percent of the spontaneous level of diseases of this type. The detection of such a relatively small "addition" to the spontaneous level is practically impossible, given the high level of annual fluctuations in the spontaneous level of carcinogenesis.

According to current estimates [13], the rate constant of DNA degradation due to spontaneous single-strand breaks is practically the same in different biological entities belonging to different radio-taxa and varies in the range $(1–9) \times 10^{-11} \times c^{-1}$, which is six orders of magnitude higher than the corresponding DNA degradation constant under the influence of radiation from an average RB ($2 \times 10^{-17} \times c^{-1}$. Based on this, we assumed that the incidence of spontaneous cancers (approximately 3000 cases per 1 million people per year) directly depends on the level of spontaneous DNA degradation and that the incidence of RB-induced cancers is in the same direct correlation with the level of DNA degradation induced by RB radiation. The proportion of RB-induced cancers should be 1×10^{-6} fraction of the spontaneous cancer rate, i.e., approximately 0.003 additional cases per year per 1 million people. Over the course of a year, 1 million people receive a collective effective dose from RB exposure of about 0.24×10^{6} cSv, which we hypothesize is likely to induce these 0.003 additional cases of cancer. Accordingly, there would be 0.012 additional cancer cases per 1 million people per year. Even over a 100-year lifetime, this risk will be equal to 1.2. Thus, the carcinogenic risk coefficient caused by IR may be at least two orders of magnitude lower than the generally accepted values of this parameter. It should also be taken into account that our estimates are obtained using the assumptions of threshold-free and linear dose-effect dependence and may be even overestimated for this reason.

It would probably be also appropriate to mention here the phenomenon of radiation hormesis, which, although still insufficiently studied to base irradiation regulation on it, is still significant evidence of the threshold effect of IR. At the same time, there are also sufficient grounds to consider a possible hormesis anticarcinogenic effect of irradiation, which, in particular, was observed in Japanese children affected by atomic bombings in 1945 – the number of spontaneous leukemia in children irradiated at a dose of 5-100 mSv decreased by 2/3 [14].

Based on the above-mentioned estimates of L. A. Ilyin and colleagues [9] and the carcinogenic risk factor calculated by us, it should be stated that the number of fatal cancers in the post-accident period should not exceed 20-30 cases, which is more than two orders of magnitude lower than the estimates of the Chernobyl Forum.

In general, a comparison of possible medical consequences (primarily deterministic effects) of the Chernobyl accident for the population with analogous consequences of other accidents shows that the Chernobyl accident ranks third in terms of the severity of medical consequences after the consequences of radioactive contamination of the Techa River and the Kyshtym accident [15]. The contamination of the Techa River was the largest radiation incident during the period when the nuclear industry functioned in the USSR. The Techa River region is the only area of the Soviet Union where the Techa River was contaminated. The Techa River region is the only place where the exposed population suffered medical consequences not only in the form of chronic radiation sickness and other radiation injuries, but also in excess infant mortality [16].

The Chernobyl accident was characterized by an exceptionally large area contaminated with radionuclides and an immeasurably larger population at increased radiation risk. However, after the Chernobyl accident, there was no increase in the number of cases of radiation sickness, no reliable increase in the incidence of leukemia and solid cancers, no increase in adverse pregnancy outcomes, no increase in mentally disabled children, and no congenital anomalies, and it has not yet been possible to identify a reduction in life expectancy. Moreover, a reduction in life expectancy by about 5 years occurred among the resettled residents of the Techa River region, but was not detected among those who remained living in their usual conditions [15].

Only insufficient surgical intervention to reduce radioiodine accumulation in the thyroid gland of children resulted in an “epidemic” of thyroid cancer. The same effects were observed in the timely unsettled Marshall Islanders exposed to radioiodine contamination in 1954. Dose levels from ^{131}I in the thyroid gland both after the contamination of the Marshall Islands and after the Chernobyl accident were significantly higher than 300 mSv, which caused an increased incidence of radiogenic thyroid cancers.

PROBLEMS OF MODERN RADIOECOLOGY AFTER THE ACCIDENT AT CHERNOBYL NUCLEAR POWER PLANT

The 39th anniversary of the Chernobyl accident is an important stimulus for analyzing the current state of radioecology. This accident sharply outlined and set before radioecology a whole range of theoretical and applied problems that required and to a large extent still require their solution. The main peculiarity of the accident is its scale and the degree of its impact on the environment, population and personnel employed in the 30 kilometers Exclusion Zone and beyond it. Of course, the main problem that has not been fully solved in Ukraine is the estimation and reconstruction of radiation doses to the population in the zone of influence of the Chernobyl accident in the most dangerous year of the acute period of the accident – 1986. According to a number of estimates, the radiation dose to people in 1986 may be from 60 to 99% of the total lifetime dose. It should also be noted that the radiation dose could be significant for the whole biota in the accident zone, which is also an important problem of modern radioecology.

As a result of the Chernobyl accident, the biotic component of ecosystems was and still is subjected to a significant dose impact from a few cGy to tens of cGy. This led, in particular, to the phenomenon of the "Red Forest" due to the death of the most radiosensitive coniferous species. Notable succession processes have occurred and are still occurring in the Exclusion Zone and surrounding areas. For instance, the number of some wild mammals increased tenfold after the accident; even red-listed species (black stork) appeared. Despite the fact that many of these phenomena are due to a significant decrease of anthropogenic pressure (for example, reducing the level of “doses” of the anxiety factor of wild animals), one should still expect radioecological consequences, since the period after the accident is insufficient for the manifestation of long-term environmental consequences (in particular, population genetic ones). In addition, due to continuous processes of radionuclide redistribution along trophic chains and ecosystem components (biota, bottom sediments, forest litter, etc.), further changes in absorbed doses in biotic components of ecosystems should be expected, and hence new consequences of them.

More than 200 different countermeasures were implemented during the Chernobyl accident consequences elimination, which formed a multitude of actions different in their effectiveness and consequences. These efforts deserve to be fully analyzed in order to assess their effectiveness and to build a universal system of countermeasures suitable for use in dealing with other types of environmental accidents (chemical, biological).

At one of the seminars of the Ukrainian Section of the International Union of Radioecologists (IUR), 30 expert participants compiled a list of almost 100 unresolved problems of modern radioecology and ranked them in terms of importance and relevance (see table). The experts rated the degree of importance and/or unresolved problems in scores from 1 to 10.

PSYCHOSOCIAL ASPECTS OF THE ACCIDENT AT CHERNOBYL NUCLEAR POWER PLANT

We are convinced that the main consequences of the Chernobyl accident for human beings are social and psychological. For example, in post- accident Europe, as a result of pregnancy termination and/or refusal to plan childbirth, more than 300,000 additional children were not born. This situation is largely due to the prevalence of radiophobia – excessive fear of possible or imaginary effects of IR. The cause of the so-called psychosomatic diseases that in their turn should be considered as mediated (in this case by the human psyche), is the nature of information perception regarding the action of IR. In this case, the human organism is affected not by the IR itself, but by excessive mental tension, which is predetermined, on the one hand, by the absence of sufficient objective information regarding the degree of threat from the IR and, on the other hand, by the presence of real information regarding the negative effects of the IR in case of acute exposure, for example, information about the death of firefighters (extinguishing big fire at the fourth block of Chernobyl NPP) from ARS. Radiophobia is considered to be a type of neurosis, namely information neurosis, predetermined by informational uncertainty (lack of information or its inadequacy), which manifests itself variously in the appearance of excessive mental stress feelings (frustrations). Even ardent supporters of the absolute threshold of the IR action do not always take into account the possibility of its mediated somatic (deterministic) influence through the human psyche. It is known that more than a half of human somatic diseases are of psychosomatic nature [17], and it is likely that some of such diseases will increase in the process of human social evolution. Of course, a person who is ill on “radiophobic grounds” is also entitled to the status of Chernobyl victim.

Table.1 Unresolved radioecological problems

Problem (task) formulation	Sum of points
Monitoring of radioecological, phyto- and zoosanitary condition of biocenoses of 30-km Chernobyl NPP Exclusion Zone	121
Development of technologies for long-term **disposal of** radioactive waste	118
Environmental **standardization of** radiation exposures	107
Environmental radiation **risks** (genetic and somatic)	106
Criteria for **criticality of landscapes** and individual components (subsystems) of ecosystems	106
Financing of radioecological research. Determination of optimal proportions of financing of fundamental and applied research	104
Ecological capacity and radio-capacity **of** ecosystems	104

Methods of **equidosimetry and dosimetry of** radiation due to elevated levels of radionuclide contamination	103
Identification of critical pathways **for radionuclide migration** beyond the Exclusion Zone boundaries	103
Development of criteria (selection of parameters) for **ecosystem sustainability**	102
Peculiarities of **"Chernobyl" radioecology** and its importance for general radioecology	102
Harmonization of risks from exposure to radiation and other factors	101
Monitoring of **uranium tailings**	101
Cooperation of radioecologists at local and global levels	100
“Destiny” of the Chernobyl Exclusion **Zone**	99
Methodological and methodological **significance of radioecology (RE)** for general ecology (radionuclides as tracers for the study of fundamental properties of ecosystems)	98
Adaptation of biota to radiation loads against the background of other factors unfavorable for ecosystems	98
Scientific support of works on further **stabilization of the ecosystems of** the Exclusion Zone.	98
Experiment (control) in radioecology	97
Self-cleaning of ecosystems from radionuclide contamination	97
Contribution of radioecology to solving the problem of "**low dose**" exposure to ionizing radiation	97
Scientific support of works on **radioactive waste** management	97
Development and application of **benefit-harm** analysis in shelter-2 construction, countermeasures and decision making	96
Selection and organization of **industrial sites** for NPP construction (organization of radionuclide- release systems)	96
Popularization of radioecological knowledge	95
Development of environmentally safe NPP **decommissioning** technology	95
Radionuclide **contamination of underground water horizons**	95
Application of **generalized parameters of** ecosystem state under conditions of chemical and radionuclide contamination	94
Teaching RE. Preparing ready-made research groups	94
Health and social RE	94
Retrodosimetry (retrofactory dosimetry)	93
"Critical **("marker")** human foodstuffs in the practice of assessment of human background radiation (BR) doses. Objective assessment of the structure and dynamics of human nutrition under conditions of radioactive contamination	93
Application of analytical geographic information technologies **(GIT)** in radioecology	92
Migration characteristics of radionuclides in ecosystems	92
Comparison of **radioecological risks** with other radiation and non-radiation risks and threats. Approaches to risk management based on assessment of their relative importance	92
Study of physicochemical mechanisms of radionuclide **migration**	91
Development of a register of **countermeasures** with recommendations for their **adaptation** to specific levels and conditions of radionuclide contamination	91
Assessment of applicability of average and maximum estimates of **radioecological risks** in conditions of uncertainty (fluctuations) of factors forming them. Standardization of approaches (algorithms) for establishing maximum estimates of radioecological risks	91
Relative Environmental Effectiveness of Ionizing Radiation (REEIR)	90

Adapting the experience of Russia and Belarus in solving agricultural RE problems (experience in applying countermeasures)	90
Relation of resistance to **chronic and acute exposure.** Predictive value of parameter estimates of **deterministic effects** for similar estimates of **stochastic effects**	90
Design (engineering) of ecosystems with specified radioecological parameters in the zone of NPP influence	89
The problem of anomalous values of **the transfer coefficient** (K_t) and accumulation coefficient (K_a) of radionuclides in the "soil-plant" system	89
Statistical aspects and specificity of RE research. The problem of extra- and interpolation in RE epidemiology	89
"Radioecological thermometer"	88
Development of a unified **radioecological terminology**	88
Creation of a unified **information base**	87
Pairing of samplers during experimental work in a real environment	87
Enhancing **ecosystem barrier functions** and optimizing the performance of water protection structures	87
Role of **isotopic and non-isotopic carriers** in radionuclide migration along trophic chains	85
Mathematical models of radionuclide behavior in the environment	84
Management of radionuclide **self-cleaning** of ecosystems	84
Development of criteria for assessing existing and prospective directions of organizing **nature reserve activities** in the Zone	84
Publishing activities, conferences, conventions, etc.	83
Methods and models for estimating **the airborne transport of** radionuclides in radiation accidents	83
Radioecological assessment of western, bog and other overwatered landscapes. Role of **landscape depressions** in radionuclide migration	83
"**Prevention" and "therapy" of ecosystems** under conditions of increased levels of radiation loads	82
Radiation and evolution. Role of radionuclide anomalies for ontogenesis and phylogeny	82
Role of **transboundary** radionuclide **transport** in ecosystems	81
Assessment of **ontogenetic radiation risks** from natural background radiation (BR)	80
Radioecology of **ultra-long-lived radionuclides** (^{36} Cl,^{99} Tc,^{129} I, Transuranic elements)	80
Landscape passportization (including retrospective) of monitoring grids, sampling points, experimental sites, plots, stations, etc.	80
The applicability of average and maximum estimates of **radioecological risks** under conditions of uncertain division (fluctuation) of forming factors. The standardization of approaches (algorithms) for setting maximum estimates of radioecological risks.	80
Successional processes in biota of ecosystems under radionuclide contamination	79
Precise **optimal agriculture** ("Precise agriculture") on radioactively contaminated soils	79
Ratio of **direct to indirect (e.g., social-psychological) RE effects** nuclear disasters	79
Relation of RE to general radiobiology, to related sciences	77
Influence of ionizing radiation in 30-km zone of Chernobyl NPP on **pathogenicity of viruses and microorganisms** for plants, animals and humans	77
Nanotechnology in RE (e.g. selective sorption of r.n.)	77
Role of **the active response function of biota** under conditions of increased radiation exposure	76

Passportization (including retrospective) of hydrothermal conditions of experimental works in real environment	76
Influence of radiation in 30-km zone of Chernobyl NPP on pathogenicity of viruses and microorganisms for plants, animals and humans. **Microbial communities** in conditions of increased RF	75
Comparability of **autoradiological and synradioecological** data	74
Optimal **organization of work** according to the RE	74
Development of systems for biodecontamination of ecosystems from radionuclide contamination	74
Radioecological **hormesis** (radioecostimulation)	74
Coordinate georeferencing (including retrospective) **of monitoring** grids**,** sampling points, experimental sites, plots, stations, etc.	73
Study of dependence of **radionuclide transfer to plants** on soil solution parameters	73
Use of the **non-interference principle** to assess total damage and pure benefit in radioecological situations	72
Study of dependence of **soil solution parameters** on physicochemical and biological parameters of soil	72
Objectivity and universality of **dose "prices"** (coefficients)	70
Assessment of **radioecological situation parameters** during different time phases of the accident (formation of post-accident radioecological situation)	67
Use of the **non-interference principle** to assess total damage and pure benefit in radioecological situations	60
Defining the **subject of radioecology** as a scientific discipline, integrating and distinguishing it from frontier disciplines, identifying the fundamental core of the discipline and it's applied aspects.	52

Let us see what psychic and psychosocial factors could influence the qualitative and quantitative dynamics of diseases of liquidators and evacuated population, as well as the rest of the population exposed to the powerful informational influence of mass media. In the post-accident period, there was one of the neurosis varieties – *hypoinformation neurosis*, caused by information uncertainty (lack and rotation of information), which manifested itself in the emergence of mental tension (frustration). The cause of such a neurosis can also be conscious informational deprivation, as was the case, for example, with Samuil Petrovich Yarmonenko, a well-known but, unfortunately, now dead radio biologist. The author personally encountered the fact that his article in one of the library issues of a radiobiological journal, in which Samuil Petrovich gave a not very favorable assessment of Ukrainian radiobiologists, was torn out. Only 38% of newspaper articles about the post- Chernobyl situation belonged to specialists (it is not known what the percentage of really professional specialists was among them). Critical ("intimidating") character was in 76% of publications.

The reactions of eyewitnesses to the accident or liquidators of its consequences were typical for people in any other extreme situation: apathy in some, euphoria in others, fear and anxiety in others. In non-professionals, group or individual infantilism, pseudo-heroism, mastery and aggressiveness were noted.

A characteristic manifestation of chronic stress is a high level of anxiety (more than 70% of those surveyed), low self-esteem of their mental and somatic health (more than 83% of people considered themselves unhealthy). There was also an exacerbation of latent somatic diseases, somatoneuroses, worsening of the course of so called stress diseases (hypertension, peptic ulcer disease, ischemic heart disease, diabetes mellitus, neurodermatitis ("stigmata"), decreased immune status of the organism, etc.). The following behavioral deviations were recorded in liquidators: dominance of psychasthenic and anxiety-phobic reactions, predominance of passive-defensive reactions to the post-ex-treme situation. Anxiety among women in the area of strict radiation control was higher than among men (90.6 and 86.3% respectively). Among women, only 5.9% felt unhealthy (which is not identical to the proportion of actually ill) compared to 21.7% of men. In liquidators (dose level from 0.2 to 1.0 Gy), no dosedependent changes in the state of the nervous system were found, i.e. no direct effect of IR was detected.

It is interesting (useful and extremely important) to note that more people with higher education or specialized secondary education (teachers, doctors, nurses), who probably had more opportunity to adequately assess the situation, felt healthy.

It has long been known that the higher the anxiety, the lower the level of positive self- assessment of health. Thus, among those who considered the situation dangerous for their health, 8.6% felt healthy, and among those who did not feel anxious – 45.4%. In the control area the level of self-assessment of health (32.9%) is 2.5 times higher than the analogous indicator for the residents of the strict radiation control. In the conditions of chronic psychological traumatic effects of the anxiety factor, one of the mechanisms of psychological defense – the defense of affect denial – was activated, which was typical for adolescents in 1987. For example, the life expectancy of adolescent schoolchildren from the Narodichesky District of Kyiv Oblast was more "shortened" (56.2 years) (about 60 years – average life expectancy of Ukrainian men) compared to the same life expectancy of their peers from Kyiv and Poltava Oblast, whose life expectancy averaged 76.4 years. Among adolescents living in areas of strict radiation control, 77.7% had health complaints. The data of in-depth examination of these adolescents revealed deviations in somato-neurological health only in 16% of those examined. The state of chronic mental stress actualizes previously existing problems of the personality, which become pathogenic for it. The population of the "affected" areas continues to experience socio-psychological discomfort, while the doses of general radiation exposure for the overwhelming majority do not exceed 0.5 cGy. This stress is exacerbated by the hard pressing of the media and the real difficulties of life.

REFERENCES

[1] Lucky, T. D. (1991). Radiation Hormesis. Boca Raton Publisher, CRC Press, 239 p.
[2] Buldakov, L. A. (2002). Medical consequences of radiation accidents for the population. Medical Radiology and Radiation Safety, (2), 7–18.
[3] Vilenchik, M. M. (1987). DNA instability and long-term consequences of radiation exposure. Energoatomizdat, 192 p.
[4] Geraskin, S. A. (1998). Regularities in the formation of cytogenetic effects of low doses of ionizing radiation: Abstract of dissertation for the degree of Doctor of Biological Sciences. Obninsk, 50 p.
[5] Geraskin, S. A. (1995). Concept of the biological action of ionizing radiation on cells. Radiation Biology. Radioecology, 35(5), 571–580.
[6] Goltsova, N. I. (1990). Influence of radioactive contamination on the structural features of Scots pine (*Pinus sylvestris L.*) (Chernobyl). Chernobyl-90: Proceedings of the 1st International Conference "Biological and Radioecological Aspects of the Consequences of the Chernobyl Accident", 1, 74–89.
[7] Grodzinsky, D. M., Bullakh, A. A., & Kolomiets, O. D. (1991). Anthropogenic radionuclide anomaly and plants. Lybid, 160 p.
[8] Ilyin, L. A. (1996). Realities and Myths of Chernobyl. ALARA Limited, 474 p.
[9] Ilyin, L. A., Kirillov, V. F., & Korenkov, I. P. (1999). Radiation hygiene. Medicine, 384 p.
[10] Keirim-Markus, I. B. (2002). Unconstructive radiation hormesis. Medical Radiology and Radiation Safety, (2), 73–76.
[11] Mikheev, A. N. (2015). Hyperadaptation: Stimulated ontogenetic adaptation of plants. Phytosociocenter, 423 p.
[12] Petin, V. G., & Pronkevich, M. D. (2012). Radiation hormesis under the action of low doses of ionizing radiation. IATE NRNU MEPhI, 73 p.
[13] Savin, V. N. (1981). The effect of ionizing radiation on an integral plant organism. Energoatomizdat, 120 p.
[14] Saurov, M. M. (2002). Estimation of the probability of lethal effects under the action of ionizing radiation on the population. Medical Radiology and Radiation Safety, (5), 5–16.
[15] Spitkovsky, D. M. (1992). Concept of the action of low doses of ionizing radiation on cells and its possible applications to the interpretation of medical and biological consequences. Radiobiology, 32(3), 382–400.
[16] Topolyansky, V. D., & Strukovskaya, M. V. (1986). Psychosomatic disorders. Medicine, 384 p.
[17] Calabrese, E. J., & Baldwin, L. A. (2000). Radiation hormesis: Origins, history, scientific foundation. Human & Experimental Toxicology, 19(1), 41–75.

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