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A system of dose-effects relationships for the northern wildlife: Radiation protection criteria

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Abstract. The key issue in the assessment system for radiation protection of wildlife is the establishment of dose-effects relationships for reference representatives of natural biota. Within the frame of the EC Project EPIC "Environmental Protection from Ionizing Contaminants" (2000-2003), a database has been created, which includes about 1600 records from 440 publications in Russian on the dose-effects relationships in wildlife from northern-temperate climatic zones. The EPIC database "Radiation effects on biota" is based on Russian/FSU experimental and field studies; chronic/lifetime exposures are the focus of the data collection. The database information covers a very wide range of radiation dose rates to biota: from below 1E(-5) Gy d^{-1} up to more than 1 Gy d^{-1}. A great variety of radiation effects are registered in the EPIC database, from stimulation at low doses up to death from acute radiation syndrome at high doses. The paper presents the dose-effects relationships for northern wildlife in the conditions of low-LET chronic irradiation. The system of dose-effects relationships forms the scale of severity of radiation effects at increasing levels of chronic radiation exposure. The system can be used as a basis for establishing criteria for radiation protection of the Northern wildlife.

1. INTRODUCTION

The key issue in the assessment system for radiation protection of wildlife is the establishment of a set of dose-effects relationships for reference representatives of natural biota, based on scientific data from a range of doses and a range of radiation effects. Risks to natural populations in particular habitats can be evaluated from a comparison of estimated doses to biota with the scale of dose-effects relationships for different types of biota.

The main concern of environmental regulations is the development of safety standards for the conditions of routine operations in the industries dealing with authorized releases of technogenic or technologically enhanced natural radionuclides to the environment, which are normally associated with chronic exposures of flora and fauna at comparatively low dose rates (well below lethal dose levels). However, in the world literature, prevailing are data on the harmful effects of high levels of irradiation [1- 4]. To fill the gaps in data, a database "Radiation effects on biota" has been created as a part of the recent EC project EPIC ("Environmental Protection from Ionizing Contaminants"); the collection contains about 1600 records from 440 publications in Russian, including radiation effects on terrestrial and aquatic animals; plants and herbaceous vegetation; soil fauna and microorganisms [5]. Chronic/lifetime exposures are the focus of the EPIC collection.

The EPIC database is based exclusively on Russian/FSU experimental and field studies of the radiation effects on wildlife from northern and northern-temperate climatic zones.

The unique feature of Russian data is the availability of long-term observations of radiobiological effects in natural conditions. Beside this, great number of publications is available on the laboratory studies of radiation effects in non-human organisms. Detailed bibliography of publications in Russian on the radiation effects in wildlife is given in the EPIC database [5].

The EPIC database covers a wide range of radiation dose rates to wild flora and fauna: from below 1E(-5) Gy d^{-1} up to more than 1 Gy d^{-1}. A great variety of radiation effects are registered in the EPIC database - from stimulation at low doses up to death from acute radiation syndrome at high doses.

This paper presents the results of data analysis on the radiobiological effects of low-LET chronic/lifetime radiation exposures.

2. SELECTION OF REFERENCE ORGANISMS

Constructing a system of dose-effects relationships for wildlife is a complicated task because of great variety of biological species existing in the biosphere, and large differences in their radiosensitivity. It is impossible to investigate the radiobiological effects in all species of flora and fauna. Instead, the system of dose-effects relationships for northern wildlife can be constructed based on a few representative (or reference) types of organisms, demonstrating different ranges of radioresistance. It is practical to select representative organisms among favorite test subjects for radiobiological investigations in the northern – temperate climatic zone.

Among terrestrial animals, the most extensive studies were carried out on small mammals, such as mice, voles and other mouse-like rodents. As mammals, mice are radiosensitive, they can be easily caught from wild populations, and the investigations can be carried out over many generations of organisms. Because of these features, mice are favorite test subjects both in field radiobiological studies and in laboratory experiments. Mice represent a reference type of radiosensitive warm-blooded vertebrate animal.

Among terrestrial poikilotermic vertebrates, frogs are popular subjects of field radiobiological studies; frogs represent a sensitive poikilotermic vertebrate animal in terrestrial ecosystems.

Among aquatic vertebrate organisms, fish are known to be the most radiosensitive species; extensive radiobiological studies have been carried out with fish and fish eggs. Sensitive species of northern fish (e.g. salmon) represent reference poikilotermic vertebrate animals in aquatic systems.

Aquatic invertebrate organisms are usually represented in the radiobiological studies by Daphnia or mollusks.

Earthworm and soft juvenile stages of insects represent the radiosensitive groups of soil invertebrate organisms and insects, respectively.

Among terrestrial plants of the northern-temperate climatic zones, pine represents a reference coniferous plant, birch – a reference deciduous plant; widespread herbaceous plants (i.e. dandelion, ribwort, etc.) – a reference herbaceous vegetation.

It is essential to note, that the selected species represent just typical species in certain radiosensitivity groups, and not the most vulnerable species. From the ecological point of view, the populations of reference species, being wide-spread and highly productive, are not very vulnerable, and have better chances to survive under radiation stress then compared with rare, or low-productive species.

3. RADIATION EFFECTS OF CONCERN IN WILDLIFE

From the wide variety of radiation effects, selected were those, which are important for the survival and reproduction of organisms in the conditions of wild nature.

Cytogenetic effects. In cells of biological tissues, radiobiological effects can be found even at low levels of irradiation; the effects appear in form of increased percentage of cells containing various aberrations in the genetic material. In the wild nature, non-repaired cytogenetic changes caused by radiation, are controlled by the process of natural selection. Organisms with genetically-reduced fitness, unable to struggle for existence effectively, are discarded from population by natural selection.

Stimulating effects of radiation. Effects of stimulation of survival and health of organisms at low doses (radiation hormesis) are discussed for many years. The stimulation effect is the result of activation of defense mechanisms in organisms, but without their exhaustion. Depending on radiosensitivity, the ranges of doses providing the stimulation effects to different types of organisms vary considerably.

Effects on morbidity. Effects of chronic radiation on morbidity of animals include the deterioration of various physiological and metabolic characteristics, which lead to a decline in health and well-being of the organisms. Effects on the morbidity in sensitive vertebrate animals include the following: (i) weakening of the immune system (increasing susceptibility to various infections; weakening of the resistance to parasite infestation); (ii) minor negative changes in blood/lymph, organs and tissues, etc.

Effects on reproduction. Reproductive organs are known to be sensitive to radiation exposure. In animals, irradiation of testes and ovaries may cause complete sterility at doses, which produce only minor changes in hematological or gastrointerstinal systems. Although damage to gonads has not much influence on the survival of an adult organism, the temporary or complete loss of reproductive capacity by many organisms in a population leads to a gradual decrease in the population size. Embryos of animals are known to be very sensitive to radiation; effects appear in the form of increased numbers of abnormalities and mortality in developing embryos resulting in the decrease of healthy progeny produced by irradiated organisms. Exposure of parents is an essential factor of damage to embryos and new-born organisms.

Mortality and life shortening. At low doses, an increase in mortality usually manifests itself as a reduction in age-dependent survival. The effect of life shortening may be a cumulative result of effects on morbidity, as well as abnormalities in reproduction, and cytogenetic damages. At the same dose rates of lifetime exposure, life shortening may have a greater effect on long-lived than on short-lived organisms. In laboratory experiments, life shortening can be determined by comparison between the average lifetime of control and exposed organisms. In natural conditions, the life shortening appear in terms of a decrease in the number of older age groups in a population.

4. PECULIARITIES OF RADIATION EFFECTS IN THE NORTHERN WILDLIFE

There are some peculiarities in the radiation responses of northern organisms, which indicate their higher vulnerability, comparing with biota from warm climatic zones. Due to long periods of low temperatures within a year, development of plants and poikilothermic animals is slower than that in warm climatic zones; for example, the development of roe of some Arctic fish species takes more than 200 days, whereas in the warm climate fish eggs are developed usually during 8-10 days. Also, the northern species usually exhibit deferred age of first reproduction in females compared with similar species in warm climate. As a result, being exposed at the same dose rate, the northern organisms receive much higher doses during the radiosensitive stages of life cycle when compared with organisms in the warm climate.

At low temperatures, radiation effects in organisms are developed more slowly; in the same time, the repair of radiation damage in cooled cells and tissues is not effective. Lesions in the cooled organisms (e.g. poikilothermic or hibernating animals) are latent. However, when organisms become warm, lesions are rapidly revealed. As a result, radiation effects may not appear during the winter, and manifest themselves intensively during the warm season.

5. A SCALE OF SEVERITY OF RADIATION EFFECTS AT CHRONIC LOW-LET RADIATION EXPOSURE

From on information, compiled in the EPIC database, the preliminary dose-effects relationships were derived, which form a scale of severity of radiation effects at increasing levels of chronic low-LET radiation exposure. The preliminary scale of dose-effects relationships for northern organisms (low-LET radiation, chronic exposure) is given in Table 1.

The development of effects with increasing the dose rates is in general agreement with the conclusions of the IAEA [1] and UNSCEAR [2] reports for terrestrial biota; for sensitive species of northern fish, the EPIC database shows the appearance of minor radiation effects at about the same dose rates as for terrestrial animals.

6. CONCLUSIONS

A general conclusion can be made, that the threshold for deterministic radiation effects in northern wildlife lay somewhere in the range 0.5-1 mGy d^{-1} of chronic low-LET radiation. In the same time, populations of highly productive vertebrate organisms (mice, some wide-spread fish species) were found to survive even at dose rates about 10 mGy d^{-1}, despite of various radiation effects.

The system can be used as a basis for establishing criteria for radiation protection of the Northern wildlife.

Table 1. Dose-effects relationships for northern wildlife, low-LET radiation, chronic exposure (based on EPIC database [5]).

Dose rates of chronic radiation exposure	Radiation effects on representative organisms of northern wildlife.
1E(-6) - 1E(-5) Gy d^{-1}	Natural radiation background for northern organisms.
1E(-5) – 1E(-4) Gy d^{-1}	No data on radiation effects above background values.
1E(-4) – 5xE(-4) Gy d^{-1}	Minor cytogenetic effects. Stimulation of the sensitive vertebrate species.
5xE(-4) – 0.002 Gy d^{-1}	Threshold for minor effects on morbidity in sensitive vertebrate animals.
0.002 - 0.005 Gy d^{-1}	Threshold for effects on reproductive organs of vertebrate animals, decrease of embryo's survival.
0.005 –0.01 Gy d^{-1}	Threshold for life shortening of vertebrate animals. Threshold for effects in invertebrate animals. Threshold for effects on growth of coniferous plants.
0.01 –0.1 Gy d^{-1}	Life shortening of vertebrate animals; symptoms of chronic radiation sickness. Considerable damage to coniferous trees.
0.1 –1 Gy d^{-1}	Acute radiation sickness of vertebrate animals. Death of coniferous plants. Considerable damage to eggs and larva of invertebrate animals.
> 1Gy d^{-1}	Acute radiation sickness of vertebrate animals; lethal dose received within several days. Increased mortality of eggs and larva of invertebrate animals. Death of coniferous plants, damage to deciduous plants.

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