Maxine Peterson
Editor

Nuclear Materials and Disaster Research

The Chernobyl Disaster

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THE CHERNOBYL DISASTER

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THE CHERNOBYL DISASTER

MAXINE PETERSON
EDITOR

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PREFACE

The massive release of radioactive material at the Chernobyl accident in 1986 led to widespread radiation exposure, in particular to people evacuated from the settlements near the reactor and workers involved in the clean-up operations, and also to several millons living in contaminated regions in Russia, Belorus and Ukraine. This book provides current research on the Chernobyl disaster. Chapter One discusses the artistic treatment of Chernobyl where the problem of apophasia arises. Chapter Two reviews the general tendencies of dynamics of frequencies of congenital malformations in the territories polluted by radioactive Chernobyl radionuclides. Chapter Three discusses the impact of low doses of radiation. Chapter Four discusses the long term consequences of atmospheric tests of nuclear weapons and Chernobyl disaster on the territory of South Bohemia in Czech Republic. Chapter Five studies the stress adaptation of microscopic fungi from around the Chernobyl atomic energy station. Chapter Six focuses on perspectives of nuclear safety. The final chapter is a short commentary on the radiation and risk of hematological malignancies in the Chernobyl clean-up workers.

Chapter 1 – This article discusses the artistic treatment of Chernobyl where we are confronted with the problem of apophasia. Writing about the indescribable seems to be a contradiction with no resolution. The main question is therefore, how can we address the unspeakable? The goal of this article is to show that a rapprochement to the unfathomable is possible in two ways: through depiction (documentary narrative) and through myth. Western authors and photographers chose a factual, documentary approach in their artistic realization of the nuclear catastrophe in Chernobyl. However, the East Slavic (here: Belarusian) artists who were directly affected by the catastrophe and the resulting trauma preferred to mythologize the event (in text and image).

Chapter 2 – The identification of frequency of occurrence, features of range and dynamics of congenital malformations (CM) in the Chernobyl territories of Belarus, Ukraine, Russia and some other countries is undertaken in this research since the period before the accident till present time. Attempt to explain some contradictory facts on CM frequencies in territories with various level of radioactive pollution are made. The significant growth in the number of newborns with CM in areas with high density of radioactive contamination is shown. Generalization of materials on prevalence of congenital malformations has formed a basis.

Chapter 3 – An international research team has analyzed their own studies and data available from the literature concerning the biological effects of chronic or acute exposure to ionizing radiation (IR) on humans and biota as a consequence of the Chernobyl accident. Mechanisms of their effects at the cellular, body, and population levels were studied and compared. It is shown that multiple somatic cell line diseases (primarily non-cancerous), which in subsequent generations lead to reduced adaptation, increased mortality and degeneration of the population, can be registered in all groups of biota including humans. Simultaneously, it is demonstrated that effects of low-dose chronic irradiation are expressed more significantly than those after one-time acute exposure of higher doses. Non-linearity of the dose-effect relationship is commonly reported as well. The authors also emphasize commonality in mechanisms of disease manifestations in many studied biological groups. Along with radiation-induced damage to DNA and genomic instability, attention is drawn to the fact, that most of the effects are not directly induced by radiation, but indirectly through regulation and through alterations in the immune and antioxidant status of the organism, which affects sensitivity to environmental factors. The response of the organism to low doses of IR is a complex function of not only dose, but of also its intensity, the time of exposure, and the time period that it takes to engage recovery (repair) systems.

Chapter 4 – Temporal and spatial changes in concentrations of selected radionuclides (tritium, radiostrontium and radiocaesium) were assessed in the parts of the Vltava and Elbe river basins affected by the operation of the Temelín Nuclear Power Plant (Temelín plant). Construction and subsequently operation of the Temelín plant initiated implementation of a number of projects, which were focused on possible impacts of the plant on the environment. The length of the series of the data that were monitored during the implementation of the projects is more than 20 years. Results of long-term monitoring (since 1990) were used for assessment of residual contamination from atmospheric tests of nuclear weapons in the last century and the Chernobyl accident. Concentrations of radionuclides were evaluated in surface water, sediments, fish and aquatic flora both affected and unaffected by waste water discharges from the Temelín plant before and during the operation of the plant. Effective ecological half-lives in surface water, sediments, fish and aquatic flora were derived. Apart of tritium the concentrations of anthropogenic radionuclides (^{90}Sr, ^{134}Cs and ^{137}Cs) downstream of the waste water discharge from the Temelín plant originate mainly from the residual contamination from atmospheric tests of nuclear weapons and the Chernobyl accident. In case of tritium the assessment was focused on an analysis of the results from sites unaffected by the Temelín plant where residual contamination from atmospheric tests of nuclear weapons was assessed.

Chapter 5 – Specialized fungi have been isolated in and around the remains of the Chernobyl atomic energy station (ChAES). To cope such environment these fungi worked out resistance mechanisms such as asexuality, synthesis of melanin like pigments, flexible morphology, and growth under limited nutrient content in the habitat. Multitrophic in nature, they possess high phenotypic plasticity. Adaptation of *Purpureocillium lilacinum* ChAES strains to low glucose (0.2%) in the medium was coupled with an increased resistance to oxidative stress. It seems to be a consequence of metabolic adaptation, and a result of melanin pigments protection. These traits might be a result of genome variations important for elucidation of stress-response elements and for understanding the evolution of extremophiles.

Chapter 6 – A summary of epidemiological studies addressing the cancer risk after the Chernobyl accident was presented in the United Nations Chernobyl Forum Report of 2006. The main finding was a dramatic increase in the incidence of thyroid cancer in children living in radiologically contaminated areas in Ukraine, Belorus and Russia. Furthermore, on the grounds of results from population based epidemiological studies, an increased risk of leukemia and other hematological malignancies among the 600,000 Chernobyl clean-up workers (or “liquidators”) was suggested. However, firm conclusions could not be drawn because of uncertainties inherent in the study designs. After the publication of the Chernobyl Forum Report three new major epidemiological investigations have been published, one cohort study and two nested case-control studies, which also conclude with an increased leukemia incidence in the Chernobyl liquidators. The aim of the present report is a critical review of these new studies.

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Chapter 1

THE SPEAKING OF THE UNSPEAKABLE: REGARDING THE AESTHETICS OF 'CHERNOBYL'

Olena Kuprina*
Department of Slavic Studies, University of Regensburg,
Regensburg, Germany

ABSTRACT

This article discusses the artistic treatment of Chernobyl where we are confronted with the problem of apophasia. Writing about the indescribable seems to be a contradiction with no resolution. The main question is therefore, how can we address the unspeakable? The goal of this article is to show that a rapprochement to the unfathomable is possible in two ways: through depiction (documentary narrative) and through myth. Western authors and photographers chose a factual, documentary approach in their artistic realization of the nuclear catastrophe in Chernobyl. However, the East Slavic (here: Belarusian) artists who were directly affected by the catastrophe and the resulting trauma preferred to mythologize the event (in text and image).

Keywords: Chernobyl, intermediality, photography, myth, comparative studies

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* Corresponding Author address: Email: olena78@arcor.de.

INTRODUCTION

The reactor catastrophe of Chernobyl was not only an ecological catastrophe, but also left widespread destruction in the field of semantics, the science of describing reality. Chernobyl has become the metaphor for the failure of one-dimensional explanatory attempts. The interest of different disciplines in the nuclear catastrophe manifests itself in numerous publications on scientific approaches to the problem (e.g., medicine, ecology, nuclear physics).[1] In the course of this article, we will illuminate it from a humanities' perspective, i.e., with the help of an intermedial lens. The theory of intermediality by Irina Rajewsky will be of special relevance to our approach. The objects of investigation are, on the one hand, the novel of the Belarusian author, Ivan Shamiakin, *Zlaia Zorka* ('The Evil Star', 1991) and images by the Belarusian photographer, Anatol Kliashchuk, and on the other hand, the novel of the Austrian author, Hans Platzgummer, *Der Elefantenfuss* ('The Elephant Foot', 2012) and photographs by the German, Rüdiger Lubricht. The pictures of both photographers were published in the volume entitled *Chernobyl 1986-2006: Living with a Tragedy*. The goal of this article is to show through an analytical overview that the accident in Chernobyl has been mythologized in East Slavic (in this case Belarusian) literary texts and photographs. Consideration of the non-Slavic (i.e., German language) materials shall demonstrate that the mythologization of Chernobyl is a specifically (East) Slavic phenomenon.

We will build on the anthropological, cultural-philosophical concept of myth[2] by Ernst Cassirer who describes myth as a world model which is defined[3] by specific mythological-magic thinking[4]. This way of thinking differs from the empirical approach mainly through sacrality, specificity,

[1] Most recently published: Mez 2010, German 2011, Varazashvili 2012.

[2] Probably no other phenomenon is enjoying such a multitude of definitions as the concept of myth. For obvious reasons we cannot present a detailed history of the development of the term in order to show the plurality of its meaning. We want to point out that several fields - anthropology, ethnology, religion studies, psychology, philosophy, literary and cultural studies - attempted to define myth. Cf. Mayer 2009, 154 and the discussion of several definitions in the most recent publications *Lust am Mythos* (Zimmermann 2015), *Die mythologische Differenz* (Matuschek & Jamme 2009).

[3] This definition reflects the traditional meaning of myth in literary criticism. The more general one is the material term: narratives about Gods and heroes and mythology as the whole of these narratives in a culture (Mayer 2009, 154).

[4] It is not possible to address the various stages in the development of mythological reasoning (e.g., totemism among indigenous people, narratives about Gods in cultural societies). More also in Cassirer 2002. For our goals, the basic differences towards empirical ways of thinking are of relevance.

syncretism, complexity, polysemantics, and ambivalence, respectively. In the mythological world, which is perceived as existing in reality, the word possesses magical powers (e.g., word magic, taboo), and the law of concrescence (of growing together) or of coincidence (of falling together) of the relational members is extant. This manifests itself in three categories: quantity (part/whole), quality (thing/attribute), and similarity (interior/ exterior).[5] This world view is reflected in mythological narratives.

In this context, mythologization signifies, on the one hand, a recourse to mythological contents: motifs, figurative concepts. A mythological figure personifies or is one of the natural phenomena. Its shape is not defined, or it may appear as a doppelwesen (zoo- and anthropomorphic). This figure is equipped with magical powers and normally has a signifying name, which expresses its essence, its central properties, or its function.[6] On the other hand, it is a construct of the world in the artistic text following the archetype of the magic-mythological world model, and it should be noted that the specific concepts of time and space are relevant. Both concepts have been shaped by the arch-categories ‘sacred’ and ‘profane’. Space is divided into a common and a sacred area, spatial directions (e.g., left/right) receive a specific mythical value; the unity of microcosm and macrocosm manifests itself in the physiological-cosmic order of the cosmic space (e.g., the creation of the world out of the body parts of a mythical figure). The mythical sacral primeval time, the time of creation, is strictly separated from the empirical profane present. This time is cyclical, ahistorical. It does not know any chronology and is understood as existing parallel to our times.[7]

In the anthropological interpretation, different people on the same level of the cultural development share the model for a mythological interpretation of the world. The forms of expression for this model change along with the development of humanity.[8] In modern society it may appear in the form of a weltanschauung - defined as superstition - or find its transformation into literary and cultural phenomena, respectively. In addition, folkloristic and Christian narratives are perceived as regional and religious forms of the myth.

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[5] The specificity of myth can only be outlined, but we will refer to comprehensive sources. For more about the properties of the mythological way of thinking, cf. Cassirer 2002, 6, 49ff., 88f., 93f.; Meletinskii 1958, 12.

[6] For more about the conception of the mythological figure, cf. Nekliudov 1972, 194f., 200.

[7] More about the mythical concept of space and time cf. Cassirer 2002, 100, 104ff., 124ff., 129ff.; Nekliudov 1972, 192.

[8] More about the anthropological theory of myth by the German folklorist, Wilhelm Mannhardt, in Perabo 2015, 78f.

The Evil Star[9]: Mythologization of Story

Shamiakin's novel describes the events in a neighboring Belarusian district after the accident in Chernobyl. Important situations, like the concealment of information, the indecisiveness and inactivity of the authorities both on the district as well as on the republic level, the delayed evacuation of the population, form the background in the description of two families whose children, Gleb and Iryna, got married at the beginning of the novel. These are the families of the chairman of the district administration, Vladzimir Pylchanka, and of the kolkhoz chairman, Ivan Pustokhod. Vladzimir's oldest son, Borys, is serving as a pilot and was already on tour in Afghanistan. The youngest son, Gleb, works as a nuclear physicist at the Chernobyl nuclear power plant. Although he had obtained leave for the wedding, he voluntarily takes part in liquidating the effects of the accident. His newly-wed wife, together with his mother, visits him in the power plant after he has not been in touch for several days. Both women were also contaminated. The novel ends with the death of the older son, Borys, who volunteers for a second tour of Afghanistan, and the death of Vladzimir's wife, Volga, who could not bear the loss of the oldest son. She also has the premonition that her second son, Gleb, who is suffering from an advanced form of radiation poisoning, will also die in the near future. The Pustokhod family loses their daughter, Liza, and her two little children remain in the care of the grandparents after her death.

The Belarusian text refers to the myth on various levels. The novel is imbedded in a folkloristic framework. It begins with a detailed description of the protagonists' wedding feast, the nuclear physicist, Gleb Pylchanka, and the medical doctor, Iryna Pustokhod. It ends with the funeral rites of Gleb's mother. In the course of the text, the author always refers to various rituals or to some of their elements, like dyeing eggs and baking Easter cakes on the Holy Saturday, the bathing ritual on Maundy Thursday ('clean Thursday' among Eastern Slavs). He also inserts quotes from folksongs (Shamiakin 1993,

[9] The title of the novel refers twice to its mythological background: on the one hand, it represents the evil fate; on the other hand, it refers to the quotation in St. John's prophecy: "And the third angel sounded, and there fell a great star from heaven, burning as if it were a lamp, and it fell upon the third part of the rivers, and upon the fountains of waters. And the name of the star is called Wormwood: and the third part of the waters became wormwood; and many men died of the waters, because they were made bitter." (Revelation of St. John 8, 10-11). Both in Ukrainian and in Belarusian, "chornobyl" and "charnobel", respectively, are different expressions for wormwood. Apparently there is no Slavic text dealing with Chernobyl which omits this allusion. Cf. just the titles: *Zvezda Chernobyl* ('The Star of Chernobyl'), *Mariia z polynom naprykintsi stolittia* ('Maria with the Wormwood Plant at the End of the Century'), *Planet wormwood*.

87f., 218, 233). The accident in the nuclear plant is defined as ‘biada’[10] (‘disaster, harm’ in English). East Slavic folklore connects ‘biada’ with guise of an old woman. The novel depicts a Ukrainian, a common, our ‘biada’, against whom they are fighting and should defeat together. Yet the phenomenon is not further described in detail. The author does not rely on the classical descriptive procedure in literature, but on a procedure, known from myth, to name figures and phenomena, respectively. According to Sergei Nekliudov (1972, 195, 200), mythological characters do not need any description, just a name. The reason that mythological characters are not described depends on the indefinability of their appearance, one of whose forms of realization may be invisibility. In the novel, these are the mortal nuclides (type of atom) that are invisible and inaudible, just as radioactivity is invisible and dangerous. Even the nuclear power plant, which does not emit any smoke comes under suspicion. The reality may be shaped by an invisible present danger (‘nevydyma prysutnist’, Hundorova 2005, 25) which cannot be described. The combination of invisibility and danger prepares the fertile grounds for the mythologization of the accident. Since a dichotomous Christian world view had already superseded the original archaic-mythological ambivalence in the collective memory, danger was associated with the demonic. Everything connected with the accident contains a diabological imagery: the reactor is the devil, the nuclear plant - hell, and the fire is diabolical (Shamiakin 1993, 202, 221).

The procedure of the mythologization is especially suited to the rapprochement to traumatic events like a nuclear catastrophe. Oksana Zabuzhko (Sabuschko 2012, 72), a Ukrainian author, already talked about her inability to write about the catastrophe after 26 April 1986, about her fear of not being able to find fitting words. Tamara Hundorova (2005, 25), a Ukrainian cultural science scholar, confirms the crisis of the word in view of the traumatic shock, since we are dealing with a (semi)apocalyptic event: old words do seem inappropriate for the new reality (not even an old ‘aesthetics’?!). The mythologization of the event, its transposition into an alogical-magic world permits us to address the unspeakable. According to the German philosopher, Hans Blumenberg (1986, 40f.), the myth mediates between humans and reality, which plague him. Myth (in the sense of the story) is used to disperse the fear of the unknown, in our case of the invisible - of the radiation. The nameless is often given a - different - name (metaphor,

[10] This has become a topos in Belarusian texts. Ivan Ptashnikaŭ, for instance, uses the same term in his short story *L’vy* (‘The Lions’, 1987).

metonym) in order to tell the story, thus gaining distance from the uncanny. The fear addressed is thus endured.

Christian components are scattered all over the text, just like the folkloristic ones. We can already see this on the character level, in the protagonists' first names of the Pylchanka family. The father carries the name of the Great Duke Vladimir (Belarus: Vladzimir), who had christianized the Kievan Rus. The mother has the same name as the first Christian woman in the Kievan Rus, Olga (Belarus: Volga). Her sons (Borys, Gleb) received the names of the first Russian-Orthodox saints, martyrs. The latter association lets us anticipate the fate of both sons. Biblical imagery runs through the text on a linguistic level: the morning after his wedding, Gleb finds no bread for breakfast in the forest house where he has spent the night with his young wife, yet he recites the Lord's Prayer (Shamiakin 1993, 78). The portrait of the oldest daughter, Liza Pustokhod, who died in a strange village after the evacuation, is being compared to an icon, the chair of the regional administration – to an archangel (Shamiakin 1993, 326, 221). The Christian orthodox rituals constitute the frame of the characters' behavior: the party members, voluntary or coerced atheists, felt a longing to pray or even to go to church; the evacuees are singing prayers before their departure and take with them icons of the Madonna (Shamiakin 1993, 218f., 293). A similar motive can be found in the photo composition *Ozhidanie* ('Waiting') (Lubricht & Kliashchuk 2006, 108f.) by the Belarusian photographer, Anatol Kliashchuk, who draws on mythologization as a process as well. The above mentioned photo composition consists of two images: in the first one, we can see a sick boy (missing hair). There are two miniature icons on the window sill: a Madonna, God, various saints. In the second image, we see the very same boy lying in bed with his gaze directed towards the sky. He is waiting for a successful cure … through a higher force. Both, the literary text as well as the photograph refer to Biblical mythology, which is solidly anchored in the collective memory. Irina Rajewsky (2002, 12f.) calls this phenomenon transmediality.

The mythical model of the world is notable for its mono-dimensionality, i.e., there is no difference between the dream level and reality, between the imagined and the true perception (Cassirer 2002, 44). In the text, this is expressed in the phenomenon of premonitions, which several protagonists experience in the context of the catastrophe. The medical doctor, Iryna, dreams of an important work awaiting her. The main protagonist, Vladzimir has the feeling of 'tryvoha' ('worry, concern') at the eve of the accident, his son, Gleb, - the morning after, when he is observing an unnatural fog (Shamiakin

1993, 77, 79, 86, 93). Volga also experiences concerns about her son, the nuclear physicist, foreseeing his death. The phenomenon of premonition is increased in the scene, where Volga, located in Belarus, sees before her how her son, Borys, is killed in Afghanistan (Shamiakin 1993, 365). The mythological space does not know any geographical borders. It also does not differentiate between object level and human level: at the end of the novel, Vladzimir is talking with the reactor, and with the earth. He accuses the reactor of having caused the death of his beloved. Earth he accuses of not offering protection. The last sentence of the novel is "The human is yelling, yet the earth does not answer" (Shamiakin 1993, 372). While the earth is known from traditional mythology (pagan, focused on nature),[11] the reactor represents a phenomenon of new mythology.

The Elephant Foot: Fiction of the Documentary

Platzgummer's text is dedicated to the events in the zone twenty five years after the accident. In the center of the text we see the fascination with the zone, where each individual is involved in their own search. The Swiss fanatic, Phillipe, is looking for proximity to God and plans to fulfill God's instructions, i.e., to let the reactor explode. He is accompanied by Soraya, who is speaks Russian thanks to her Russian grandmother. The Austrian student, Henry, would like to write a dissertation about animal mutations in the zone. Three Ukrainian soldiers, searching for adventures and freedom from their commander, are having a picnic.[12] One of the soldiers kills Phillipe on his way to the reactor and unwittingly prevents his mission. The ex-nuclear physicist, Igor, whose wife had died of radiation poisoning, is running a gas station in the zone and has dedicated himself to astronomy. At night, he is observing those stars particularly close to the zone. As a child, the survivor, Aleksandr happened, unfortunately, to be visiting his grandparents who lived in the

[11] The earth is firmly rooted in in the mythical, East Slavic folklore tradition and - as in many other cultures - is equated with the mother figure. Regarding the earth motif in Belarusian texts, cf. Prokhar 2007, 2012). Oksana Zabuzhko (Sabuschko 2012, 61f.) is also talking about the pantheism in Ukrainian culture to which representatives of other (Western) cultures cannot relate.

[12] This might be a hidden reference to the text by the brothers Strugatskii, *Piknik na obochine* ('Picnic by the wayside', 1972), which forms the basis for Andrei Tarkovskii's film *Stalker* (1979). It is about a mysterious area, called the 'zone'. Strange events take place here: the zone is unknown, it is guarded by military. Zabuzhko (Sabuschko 2012, 86) considers it to be an omen for Chernobyl.

vicinity of Chernobyl, and discovered his closeness to the zone. He had undergone a trepanation so that the damaging elements could leave his head unhindered.

As the Austrian author had not been directly affected by the Chernobyl accident, it allowed him to write about it in a detached way: he juxtaposes its mythologization in the Belarusian text with a factual, documentary, even naturalistic approach. It is marked by an exact chronology. The story takes place within nine days (from Saturday, 11 June 2011 to Sunday, 19 June 2011) and is complemented by temporal jumps into the more distant past (with Aleksandr and Igor back to the time of the accident) and into the more recent past (when Soraya met Phillipe half a year ago). The course of six days (06/11, 06/15-06/19) is described in detail, in two lines of events which are separated in space: On 11 June, for instance, Soraya and Phillipe's action are printed on the top of the page, while Igor and Aleksandr on the bottom part. There are only two exceptions: Chapter I dated June 19, where insects and animals are the sole protagonists, gradually dismembering Phillipe's body; and chapter IV (Jun 16), which gives an account of Henry's notes.

In the Belarusian novel, there is barely any information as to what happened on April 26. The Austrian novel reports in detail about the experiment from the view of the scientist, the nuclear physicist, Igor. It also describes the following scenes: plunderers, returnees, tourists, and also the court trial of the director of the nuclear plant, Viktor Briukhanov. Further information is added by the future scientist, the biology student, Henry: the killing of the cattle, the deployment of Soviet military. The fiction of the documentary is suggested both by Henry's notes which form an entire chapter, and by the media combination (a term coined by Rajewsky). Here the author reverts to the medium of photography which is traditionally associated with authenticity.[13] Thus, the cover of the book displays a photo with gas-masks. On the hardcover, we find the warning sign for radioactivity (DIN 4844-2), the color of the hardcover is yellow, just like the background of the warning sign.

[13] While literature is primarily characterized through its fictionality, recipients have associated photography with authenticity since its inception, in the sense of "verifiable reference within the extra-medial reality" (Hillenbach 2012, 40). Researchers on photography prefer the term 'indexicality'34 over the term 'authenticity', defined as problematic. Indexicality is about the reproduction of an object present (having stood) in front of the camera, yet the free choice of the photographer's design possibilities are not excluded (Hillenbach 2012, 47f.). The term is derived from the Pierceian differentiation between three types of signs: symbol, icon, and index, which display different modes of how to connect to the referent. While the symbol (word) is arbitrary, and the icon (image) is connected to its referent by its similarity, index proves the existence of the referent (Hillenbach 2012, 53). Photography is primarily defined as an index, yet it also carrying iconic traits.

A photo is included after each chapter: altogether there are four photographs, three of them showing the streets and buildings of the deserted town of Prypiat and one repeating the image from the cover. These photographs are by Boris Chykulay. In addition, we can discern intermedial references (in the sense of Rajewsky) in the text. While Igor is watching Henry handling the Geiger counter, he is thinking: “Today the foreigners are taking photos of the evacuated kindergarten in Prypiat, of the dolls and picture books collecting dust on the ground, of gymnastic shoes, teddy bears, or half-finished children’s drawings” (Platzgummer 2012, 119). All the images, described in the quote, refer to the pictures by Rüdiger Lubricht (Lubricht & Kliashchuk 2006, 39, 40, 42, 43) in the above-mentioned volume. The marking is missing in a different location: Henry’s reflections on the animal world in the zone - “horses that seemed healthy and strong and did not display any mutations like the domestic horse, which was born in 1987 with eight extremities at a Russian sovkhoz about eighty kilometers from Chernobyl” (Platzgummer 2012, 103f.) - refer to the well-known photo of the eight-legged horse by Ihor Kostin (2006, 160f.). Neither the photographs nor the names of the photographers are credited in the book. When referring to the medium of photography (at least in the first example), one could miss the connection, if one is unfamiliar with the images.

The mythological foundations - both the religious as well as the pagan-folkloristic ones, central to the Belarusian text, are negated in the Austrian text, i.e., by the representatives of the non-Slavic, Western culture: the Swiss, Phillipe, criticizes superstition, even when he has to admit that the accident had furthered superstition (Platzgummer 2012, 163f.). It is true that Phillipe is searching for God in the zone, but his God does not share any similarities with the Christian orthodox one of Soraya. On her first day in the zone, a disoriented Soraya feels the desire to recite the prayers of her orthodox grandmother. The suggestion to pray is firmly rejected by Phillipe. Fearing a beating, Soraya does not insist on her wish. Henry also evokes the third angel here, known from St. John’s prophesies, but in a somewhat condescending tone to attract religious freaks (Platzgummer 2012, 66ff., 135).

The key terms in the Austrian text are ‘death’ and ‘life’. In the mythological tradition, both represent two parts of a being, of a cycle: birth is understood as return and death as continuation (Cassirer 2002, 45). The novel separates both spheres and is mainly interested in the physical dimensions of death. It begins with the naturalistic description of a corpse in the forest. The author describes in detail how the body decomposes, which insects and animals dismember the body in what sequence until it has been completely disposed of by nature (Platzgummer 2012, 77). The corpse is mentioned a second time in the penultimate chapter, when we are informed that this is Phillipe who had been killed by the drunk soldier, Oleg, on his way to the reactor (Platzgummer 2012, 196ff., 200). In a third instance, the corpse is represented in Henry's perception (Platzgummer 2012, 211ff.). In all three cases, the author primarily addresses the details of decomposition: the dead person loses his dignity, is condescendingly referred to as a bundle of flesh and bones. Aleksandr's grandparents who are dying from the effects of contamination provide of the experience: the grandmother is lying for several days next to her dead, decaying husband and is awaiting her own death (Platzgummer 2012, 64ff.). The Belarusian text mentions the death of the two female protagonists, Liza Pustokhod and Volga Pylchanka, as well, but in both cases, the emotional dimension of the tragedy is placed in the foreground: the narratives of the grieving family, of its crying children and parents, do touch the reader (Shamiakin 1993, 284ff., 370f.).

The dichotomy of life and death as the central topic is not limited to the conversations of the protagonists. Two semantic poles are constructed in the text. Everything belonging to the zone is attributed to the adjective 'dead': the zone is dead, the city and the ground, streets, machines, plants, and trees are dead. Everywhere there are 'mogilniki' (graves) (Platzgummer 2012, 9, 98, 101, 103, 104). The survivors, Aleksandr and Igor, belong to the semantic space of 'death', but so does the fanatic, Phillipe. They define themselves as dead (Platzgummer 2012, 102, 178, 237ff.). Soraya, though, wants to live. She wants to leave the zone as quickly as possible as she senses that the stay there and the effects of death connected to it will not only leave traces in her soul, but even physically - in her face. She looks at her mirror image and perceives "a gray, haggard face, lifeless eyes full of fear, deep, dark rings under them, a woman more dead than alive" (Platzgummer 2012, 178, 207). The biology student, Henry, attempts to adopt an intermediary position by defining the zone as a place of death for people, but also as a place of life for nature which had received the chance to reconquer its territories thanks to the explosion of the reactor and the withdrawal of the humans. Henry expects to be able to observe various mutations in the animal world. He is fascinated by nature (Platzgummer 2012, 105, 129). We can observe a similar approach in the images of the German photographer, Rüdiger Lubricht. Many of his photographs show flora regaining the upper hand (Lubricht & Kliashchuk 2006, 76, 77). He also has a rather scientific and factual interest in the accident and its consequences, respectively. Other photographs taken by him confirm this, documenting the nuclear power plant, the abandoned technology, and the abandoned city (Lubricht & Kliashchuk 2006, 22, 50, 30, 31).

In the novel, the semantic field 'death' is associated with silence (Platzgummer 2012, 7, 13). While Aleksandr, Igor, and Phillipe are enjoying the silence of the zone, Soraya is seized with panic by this deathly silence. She attempt to fight it through speaking (area of life) and talks, even screams at Phillipe, while Henry does not directly admit that he cannot tolerate the silence of the zone either. The constant "communication with his recorder reveals his fear" (Platzgummer 2012, 49, 96, 116, 121f., 132ff., 149f., 158). Henry does not keep this intermediate position all through the end of the novel. After he was unable to find any mutants, and instead discovered a corpse in the forest, he has no doubt that the zone is not nature's paradise, but a place of dying and killing: "He now knew that this silence was deadly, a dying, a killing" (Platzgummer 2012, 217). Soraya is also convinced that it is a place where there is nobody: "No human, no animal far and wide. No God." (Platzgummer 2012, 219).

Conclusion

The analysis sketched here shows us the following: the Western authors and photographers chose a factual, documentary, naturalistic, and partially philosophical approach to the artistic realization of the nuclear catastrophe in Chernobyl. The East Slavic (here Belarusian) authors, however, were directly affected by the catastrophe and preferred a mythologization of the story (in text and image) due to their trauma. In order to name the unspeakable of the catastrophe they chose the culture-specific reference to a mythological, to an alogical-magic world. The new mythological ('explanatory') frame possibly makes it easier to address and to cope with the unspeakable.

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Chapter 2

CONGENITAL MALFORMATIONS AT THE CHERNOBYL TERRITORIES AND AMONG POSTERITY OF LIQUIDATORS (REVIEW)

Anton Korsakov[1,*], Alexey Yablokov[2] and Emilya Geger[3]

[1]Bryansk State Technical University,
Department of Safety and Chemistry, Professor,
Doctor of Biological Sciences, Bryansk, Russia

[2]Institute of Biology of Development of Koltsov of the Russian Academy of Sciences, Counsellor of RAS, corresponding Member of RAS, Professor, Doctor of Biological Sciences, Moskow, Russia

[3]Bryansk Clinical and Diagnostic Center Department of Health Care of the Bryansk Region, head of Department of Medical Statistics,
Doctor of Biological Sciences, Bryansk, Russia

ABSTRACT

The identification of frequency of occurrence, features of range and dynamics of congenital malformations (CM) in the Chernobyl territories of Belarus, Ukraine, Russia and some other countries is undertaken in this research since the period before the accident till present time. Attempt to

[*] E-mail: korsakov_anton@mail.ru.

explain some contradictory facts on CM frequencies in territories with various level of radioactive pollution is made. The significant growth in the number of newborns with CM in areas with high density of radioactive contamination is shown. Generalization of materials on prevalence of congenital malformations has formed a basis.

Keywords: congenital malformations, the Chernobyl catastrophe, radioactive contamination density

INTRODUCTION

The additional ionizing radiation breaks a normal embryonal development and leads to developing of malformations – physical anomalies, violations of a metabolism and to genetic defects. These violations depend on the level of radiation and stage of the embryonal development (at which radiation took place). The ionizing radiation causes mutations in gametes of parents (which lead to emergence of CM) and it is the factor breaking processes of pre-natal development at its early stages. The radionuclides incorporated in a maternal organism can cause an embryonic dysplasia, structural and functional changes in the developing bodies and fabrics of the embryo and fetus, neonatal pathologies (ICRP, 2003; BEIR, 2006).

As a result of the Chernobyl accident the huge amount of the radionuclides has been thrown out into the environment which has led to additional short-term radiation of many millions (generally in Europe). Radioactivity, is defined, generally by long-living Cesium-137 (^{137}Cs) and Srontium-90 (^{90}Sr). 30 years later after accident in the radiation polluted territories of Ukraine, Belarus and Russia radioactivity will remain high for several decades (Izrael, Bogdevich, 2009; Onishchenko, 2009; National reports of Ukraine, Belarus and Russia, 2011).

In the first years after the Chernobyl accident the increased CM frequencies in Belarus (Lazyuk et al, 1996, 1997, 1999; Kulakov et al., 1993; Savchenko, 1995; Dzikovich, 1996), Ukraine (Kulakov et al., 1993; Orlov, 1995; Grodzinsky, 1999; Evtushok, 1999; Stepanova, 1999), European part of Russia (Baleva et al., 1996; Burlakova et al., 1998; Fetisov, 1999; Ivanov et al., 2002), Germany (Korblein et al., 2000; Hoffman, 2001), Turkey (Akar et al., 1988) and other territories. The subsequent supervision have shown steady increase in frequency of occurrence of CM in the radioactive polluted territories of Belarus, Ukraine and Russia (National reports), and among posterity of liquidators (Stepanova et al., 2002; Tsyb et al., 2004; Horishna, 2005; Matveenko et al., 2005; Sipyagina et al., 2006; Zotova, 2007; Ermalitsky, 2011, 2013) are found. On the other hand it has become clear that in some radioactive polluted territories the essential increase in frequency of CM wasn't observed (Korsakov et al., 2014).

In the present article we try to reveal the general tendencies of dynamics of frequencies of CM in the territories polluted by radioactive Chernobyl radionuclides. The experience has formed a basis. It was got in the analysis of distribution and dynamics of CM on the most radioactive polluted territory of Russia after Chernobyl – the Bryansk region (Korsakov et al., 2014).

Publications, containing data on CM frequencies in the territories polluted by the Chernobyl radionuclides, are of several hundreds. The majority of data is published in inaccessible editions. Below the review of those publications which were available is given. At first material on Belarus, Ukraine and Russia, then on other countries is given. Data on CM frequencies among posterity of liquidators – the persons who have received additional radiation during emergency works on the Chernobyl NPP in 1986 – 1988 are considered separately.

THE REVIEW OF DATA ON CM ON THE RADIOACTIVE POLLUTED TERRITORIES AS A RESULT OF THE CHERNOBYL ACCIDENT

At first, in a tabular form, the contents of the analyzed publications on dynamics and prevalence of CM are briefly described on the radioactive territories polluted as a result of the Chernobyl accident. Then data on dynamics of different CM in concrete territories are analyzed in more detail.

Table 1. Congenital malformations in the territories of Belarus polluted by the Chernobyl radionuclides

Frequency of CM	Group of newborns/abortus	Author
Substantial growth after 1986	All newborns of the country	
Gomel and Minsk regions, and also rise for 49% in 17 more radioactive polluted areas for 1987 – 1988 and for 17% – over all country during the period 1987 – 1994	Yearly and monthly frequencies of cases of Down syndrome for 1981 – 1999 (2786 cases)	Lazjuk et al., 1997

Table 1. (Continued)

Frequency of CM	Group of newborns/abortus	Author
Growth by 1,8 times from level 1982 – 1985 in the next eight years (1987 – 1995) (respectively 3,9% and 7%)	Newborns in 17 regions of Belarus polluted by ^{137}Cs at the level >555 kBq/m^2	Lazjuk et al., 1997 (cont'd)
Growth in more polluted territories of the anencephalia, spina bifida, cleft lip/ palate, polydactyly, reduction of extremities, esophageal atresia and atresia of anus, Down syndrome and multiple CM	All medical abortuses during 1982 – 1985 and 1987 – 1994 at the territory of administrative regions with pollution >555 kBq/m^2, 37 – 555 kBq/m^2, <37 kBq/m^2	
Increased by 1,7 times (respectively, 5,6 and 9,4 for 1000)	All newborns of the country for 15 years after Accident	Nat. report Belarus, 2006
Growth in territories with pollution <37 kBq/m^2 – for 24%, in territories with pollution of 37 – 185 kBq/m^2 – for 30%, in territories with pollution ≥ 555 kBq/m^2 – 83%	Newborns, in territories with a pollution density of ^{137}Cs at the levels <37 kBq/m^2, 37 – 185 kBq/m^2, and ≥ 555 kBq/m^2, first 10 years after Accident (1986 – 1996)	Institute of radiology Belarus, 2006
Growth for the first five years on more radioactive polluted territories, in the second five years – on less polluted territories	Newborns, in territories with a pollution density of ^{137}Cs at levels < 37 kBq/m^2, and 37 kBq/m^2, by five years before and after accident	Nat. report Belarus, 2006
Increase more than for 40% (from 12,5 on 1000 childbirth in 1985 to 17,7 in 1994), bigger in territories with pollution > 555 kBq/m^2	All newborns of the country and at the territories with pollution on ^{137}Cs > 555 kBq/m^2 in 1994 and in 1985	Lazjuk et al., 1996 a
Six times higher, than in 1985	Newborns in territories with pollution level on ^{137}Cs at the level ≥ 555 kBq/m^2 in the Gomel region in 1985 and in 1994	Lazjuk et al., 1996 b
Statistically significant grow	The newborns who have died from CM of nervous system, 1986 – 1996	Dzikovitch, 1996
Peak in January, 1987 (among the children conceived during the first days after Accident). Territorial distribution of children repeats a trajectory of the movement of radioactive clouds	Monthly frequencies of newborns with a Down syndrome, 1983 – 1999 with a Down syndrome	Lazjuk et al., 2004
Growth on a polydactyly, a reduction of extremities, esophageal atresia and atresia of anus and on multiple CM, the maximum values in the first two years after accident, on an anencephalia, myeloceles, cleft lip/palate, – in later terms (1990 – 2004)	Newborns in 17 more and 30 less radioactive polluted areas during five years before and after the Accident	Nat. report Belarus, 2006

Frequency of CM	Group of newborns/abortus	Author
In the first years it have significantly increased at more radioactive polluted territories, then increase has happened also on less polluted territories. The most significant growth was noted on a polydactyly, reducing defects of extremities and multiple CM during 1987 – 1989 in the most radiation polluted areas	Newborns in 17 administrative regions with average pollution on ^{137}Cs at the level ≥ 185 kBq/m^2, and 30 less (≤ 37 kBq/m^2) polluted administrative regions of the country (492 514 thousand people) before and after the Accident, 1981 – 2006	Zatsepin et al., 2007
Growth of frequency of polydactyly by 1,3 – 2,7 times in the territories polluted on ^{137}Cs at the level <37 kBq/m^2, and by 10 – 14 times – in territories with pollution ≥ 555 kBq/m^2	Newborns in the Gomel and Mogilev regions before, and within 12 years (1997 – 1998) after Accident	Naumtchik et al., 2001
Growth the frequency of reducing defects of extremities – seven times in areas of the Gomel region with pollution level on ^{137}Cs ≥ 555 kBq/m^2, and by 1,2 – 2,5 times in less radioactive polluted areas		
Growth of frequency of multiple CM by 2,2 – 2,3 times in more radioactive polluted districts of the Gomel and Mogilev regions, and by 1,4 – 1,8 times in less polluted regions		
Growth in territories with pollution level on ^{137}Cs ≥ 37 kBq/m^2, is especially strong – in territories with pollution ≥ 555 kBq/m^2 in Gomel and Mogilev	All spontaneous abortions (abortuses) about the country for 1986 – 1996 (more than 31 thousand)	Lazjuk et al., 1999 a, b
Growth in territories with pollution < 37 kBq/m^2 of the Mogilev and Gomel regions, compared with Minsk (by 1,5 times – the general frequency, polydactyly frequency – by 1,3 times, the frequency of multiple defects of extremities – by 2,8 times)		

Table 1. (Continued)

Frequency of CM	Group of newborns/abortus	Author
Statistically significant growth	Abortuses from districts of the Gomel and Mogilev regions with pollution > 555 kBq/m^2 in 1986 – 1988 (n = 617) compared with abortuses from areas with pollution < 37 kBq/m^2	Feshchenko et al., 2002
Growth by 2,0 – 6,8 times (it is correlated with pollution level) with a growth in the country by 1,2 times	All newborns of the Gomel region on the radioactive polluted territories of the towns of Chechersk, Vetka, Hoyniki, Dobrush and Elsk in 1982 – 1985 and in 1987 – 1989, compared with newborns about the country	Savchenko, 1995
Growth twice (with 5,2 to 10,5)	Newborns of Chechersky district of the Gomel region of 1983 – 1985 and 1986 – 1990	Kulakov et al., 1993
Growth is correlated with the level of radioactive pollution: Gomel region by 1,5 times, Mogilev region – by 1,3 times, Brest region – by 1,2 times, Vitebsk region – by 1,1 times	All newborns of the Mogilev and Gomel, Brest and Vitebsk regions, 1981 – 1993	Petrova et al., 1997

Table 2. Congenital malformations in the territories of Ukraine polluted by the Chernobyl radionuclides

Frequency of CM	Group of newborns	Author
Growth by 5,7 times	Newborns of all country, 1987 – 1996	Grodzinsky, 1999
1,9 times higher (5,52 ± 0,22 and 2,95 ± 0,18; $p < 0{,}001$); CM range differs	Newborns at evacuated people, and in territories polluted by ^{137}Cs at the level ≥ 37 kBq/m^2, compared with territories < 37 kBq/m^2	Stepanova, 1999
Higher frequency of multiple CM, polydactyly, deformation of internals, reducing defects of extremities and abort	Newborns and in territories polluted by ^{137}Cs at the level of ≥ 37 kBq/m^2, compared with territories < 37 kBq/m^2	Horishna, 2005
Frequency of CM of a nerve tube is 1,8 times higher, anencephaly – by 2,1 times, microcephaly – by 2,6 times, ano- and microphtalmia – by 1,6 times, a congenital cataract – by 2,2 times	All newborns of the Ukrainian Polissia, 2005 – 2008 (in comparison with Central European)	Dancause et al., 2010)

Frequency of CM	Group of newborns	Author
On the average in the area, growth from 15,3 to 37,3 (per 1000 newborns), in more radioactive polluted northern areas growth is higher	Newborns of the Rivne Region, 1986 – 1996	Evtushok, 1999
Growth of number of CM of nervous system (for 98% – hydrocephaly), with average annual increase by 39%. The appealability peak (663 cases) was in 1990	Newborns with CM of nervous system coming to clinic of Institute of neurosurgery of AMS of Ukraine, in seven years after (1987 – 1994, 4925 cases) compared with five years before Accident (1981 – 1985, 2209 cases)	Orlov, 1995
Frequency of CM of the central nervous system (CNS) on more radioactive polluted territories is 1,5 times higher (respectively, 2,7 and 1,8 for 1000). Frequency of a microcephaly is 2,8 times higher (respectively, 0,37 and 0,13 for 1000), microphtalmia – is 4,5 times higher (respectively, 0,18 and 0,04 for 1000)	All newborns of the Rivne area (96 438 people) of 2000 – 2006	Wertelecki, 2010
Occurrence of conjoined twins is three times higher, and occurrence of a teratoma (cancer of coccygeal region of spine) in two – three times is higher, than on average in the European countries	All newborns of the Rivne area (96 438 people) of 2000 – 2006	Wertelecki, 2010
Average frequency to Polissia (in more radioactive polluted part) 1,4 – 3,1 times higher, than in less polluted areas	All newborns of the Rivne area 2000 – 2012	Yevtushok et al., 2013; Wertelecki et al., 2014 a
Down syndrome frequency in Polissia is 11% higher		Wertelecki et al., 2014 a
In the radiation polluted areas it is higher (for 7,8%). Frequency of CM of nervous system is 45,3% higher	Live-born of Zhytomyr region (147 318 people) of 2000 – 2010	Timchenko et al., 2014

Table 2. (Continued)

Frequency of CM	Group of newborns	Author
Frequency of CM of bone and muscular system above average data on Ukraine by 2,7 times	Newborns of the Chernivtsi region, 2004 – 2008	Pishak et al., 2012
At the sibs who were born after Accident the phenotype with multiple small anomalies of development is formed (is not unique to the sibs who were born before Accident)	Newborns before and after Accident at the parents irradiated as a result of Accident	Stepanova et al., 2002 a
The number of small anomalies is correlated with radiation level	The newborns irradiated with *in utero*	Stepanova et al., 2002 b
The number of small anomalies is more at appeared during "the iodic period" at earlier stages of pre-natal development	Newborns (1144 children) evacuated from Pripyat and at mothers living on radioactive polluted territories	Nat. report Ukr., 2011
Growth	Children at territories with pollution $\geq$ 37 kBq/m^2, 1987 – 2010	Nat. report Ukr., 2011
On more radioactive polluted areas 1,6 – 2,8 times higher, than in less polluted territories	Newborns in territories with pollution on ^{137}Cs at the level $\geq$ 37 kBq/m^{2}compared with newborns in territories with pollution on caesium-137 at the level < 37 kBq/m^2	Horishna, 2005
The number of small anomalies of development 8 – 11 is higher (respectively, from 7 – 14 and 5 – 6). In the first group the frequency of the deformed earflap and a partial webbed fingers is higher	Newborns of the irradiated parents (100 people) compared with newborns (60 people) of unirradiated	Demenkova et al., 2011
Growth by 3,1 times (with 6,8 to 21,3) totally CM of an esophageal atresia, an anencephaly, hydrocephaly, multiple CM	Newborns of the Polissia district of the Rivne region 1983 – 1985 and 1986 – 1990	Kulakov et al., 1993

Table 3. Congenital malformations in the territories of the European part of Russia polluted by the Chernobyl radionuclides

Frequency of CM	Group of children	Author
1,5 times higher	Newborns in territories of 37 kBq/m^2 polluted on ^{137}Cs at the level ≥37 kBq/m^2 compared with newborns in less polluted territories, 1993 – 1998	Burlakova et al., 1998
Growth by 3 – 5 times	The newborns in southwest territories of the Bryansk Region polluted on ^{137}Cs above ≥ 555 kBq/m^2 in 2001 compared with 1987	Ivanov et al., 2002; Fetisov et al., 2006
Growth of frequency of a hypospadias in 6,2 and cleft lip and palate by 1,4 times in comparison with data of the international register at not excess on other CM of the strict account	Newborns in southwest territories of the Bryansk Region, 1999 – 2004	Kapustina, 2005
Growth at more radioactive polluted territories	Newborns in territories polluted with ^{137}Cs at the level of ≥37 kBq/m^2 compared with newborns in the territories which were less polluted 1987 – 1996	Baleva et al., 1996; Ivanov et al., 2002
Multifactorial CM are met more often at the radioactive polluted territories	Newborns in territories polluted with ^{137}Cs at the level of ≥37 kBq/m^2 compared with newborns in the territories which were less polluted	Liberman, 2003
On SWT on the first place – CM of bone and muscular system (which are met seldom)	Newborns in the radioactive polluted districts of the Bryansk Region compared with newborns about the country	Yakovleva et al., 2003
Prevalence of CM of bone and muscular system	Newborns of territories of the Bryansk region with pollution on ^{137}Cs at the level of 185 – 1665 kBq/m^2, 1986 – 1995 (301 children)	Bondarenko et al., 2004

Table 3. (Continued)

Frequency of CM	Group of newborns	Author
One and a half time higher, than for area in general	Newborns of territories of the Bryansk region with pollution on ^{137}Cs at the level of 185 are 1665 kBq/m^2, 1995 – 1998 compared with newborns of all area	Fetisov, 1999
In more radioactive polluted areas for 16% on the general and for 22% on primary above regional average; by 3,8 times on the general and by 12,5 times on primary above, than in the small polluted area	All newborns of the Bryansk region, 1991 – 2012 (data of official medical statistics)	Korsakov et al., 2014
Higher in Klintsy and Klimovskiy areas, despite their smaller (compared with other administrative regions of SWT) pollution density with ^{137}Cs and ^{90}Sr	Newborns in the different levels of radioactive pollution (from 68 to 573 kBq/m^2) strongly polluted areas of the Bryansk region with ^{137}Cs, 1991 – 2012	Korsakov et al., 2014
The maximum frequency is in the most radioactive polluted area in the second fifth anniversary after Accident (1991 – 1995). In 15 years (1996 – 2000) CM frequency in strongly and less polluted areas became equal	Children's population of the Kaluga region 1981 – 2005	Omarashabov, 2007
Higher in more radioactive polluted areas	Newborns of the Kaluga region of 1986 – 2001	Ivanov et al., 2002
Four times higher, than for the children's population of all area	Newborns of the Kaluga region of January – April, 1987 (which were *in utero* at the period of “iodic blow”)	Tsib et al., 2006
Growth in three times. In a greater degree the number of violations of development of genitals, a congenital cataract, malformations of nervous system and sense organs, bone and muscular system and digestive organs increased	Newborns of the Oryol region of 1986 – 1992 in territories polluted on ^{137}Cs at the level of $\geq$ 37 kBq/m^2	Kulakov et al., 2001

Table 4. Congenital malformations on the radioactive polluted territories of other countries

Frequency of CM	Group of newborns/abortus	Author
Growth of frequency of CM of CNS	All newborns of Austria before and after Accident	Hoffmann, 2001
Growth of frequency of CM of heart, CNS, multiple CM	Newborns of the Plevna area, Bulgaria	Moumdjiev et al., 1992; quoted after Hoffmann, 2001
Growth of frequency of CM of CNS	All newborns of Hungary	Hoffmann, 2001; Schmitz-Feuerhake, 2002
Growth	All newborns of Germany, 1987	Korblein, 2000
Growth of frequency of CM of CNS and abdominal wall	Newborn 1986 – 1987 in Yen in comparison with 1985	Lotz et al., 1996, quoted after: Hoffmann, 2001
Growth of CM of abdominal wall, cleft lip and palate and CNS (above in more radioactive polluted areas)	Newborns in the territory of the former GDR in 1987 compared with newborn 1980 – 1986	Zieglowski, Hemprich, 1999
4,2% in 1986, 8,7% in 1987 (from them 22% of CM of extremities, 15% – cardiac, 8% – a hypospadias, 8% – cleft lip and palate)	Abortuses, the Western Berlin, 1986 – 1987 (n = 739)	Busby et al., 2016
Growth in November, 1986.	Newborns of Bavaria, 1986 – 1987	Korblein, 2002
Growth by 2,5 times among conceived in May, 1986.	Down syndrome among newborns of the Western Berlin of 1986 – 1987	Wals, Dolk, 1990
Growth at deadborn	Newborns of Western Berlin, 1986 – 1987	Hoffman, 2001
Growth of frequency of CM of heart, face, jaw, neck, backbone, joints, foot and long bones of legs	Newborns of Bavaria	Scherb, Weigelt, 2003, 2010
Growth of frequency of cleft lip and palate (more considerable in more radioactive polluted Adjara and Rache)	Newborns of Georgia	Vephvadze et al., 1998
Growth of frequency of CM of CNS near Odense	Newborns of Denmark	Hoffmann, 2001; Schmitz-Feuerhake, 2002

Table 4. (Continued)

Frequency of CM	Group of newborns/abortus	Author
Growth in the southeast of Moldova, more considerable at more radioactive polluted territories	Newborns of Moldova, 1989 – 1996 (8 509 people)	Grigoriy et al., 1998
Growth of frequency of hydrocephaly on more radioactive polluted territories, decrease in frequency of a Down syndrome	The newborns of Norway conceived during the period May, 1983 – April, 1989	Terje Lie et al., 1992
Growth of frequency of a microcephaly	Newborns of Norway 1987	Ulstein et al., 1990
Growth of frequency of CM of CNS in more polluted (splitting of a backbone, anencephalia, encephalocele et al.) by 2 – 7 times	Newborns of Turkey, 1986 – 1987	Akar et al., 1988, 1989; Akar, 1994; Caglayan et al., 1990; Mocan et al. 1990
Growth in average and strongly radioactive polluted areas. CM of CNS and a reduction of extremities met more often	The newborns of Finland who were born in February – December, 1987	Harjuletho et al., 1989, 1991
Growth	Abortuses and deadborn of Croatia, 1980 – 1993 (data of university clinic of Zagreb, 3 541 children)	Kruslin et al., 1998, on: Schmitz-Feuerhake, 2002
Growth in 1987 (in eight years prior to Accident frequency was almost identical)	Newborns of the Czech Republic, 1978 – 1989	UNICEF, 2005
Growth of frequency of a Down syndrome in more radioactive polluted northeast areas	Newborns of Sweden, 1987	Ericson, Kallen, 1994
Growth of frequency of a Down syndrome in 1987 (in comparison with a long-term trend) on most radioactive polluted territory	Newborns of Scotland, 1979 – 1989	Ramsay et al., 1991

Table 5. Peculiarities of occurrence of CM in children of liquidators on the CNPP

Frequency of CM	Group of newborns	Author
Three times higher (37,7% against 12,5% in control)	196 children of liquidators of the Rostov Region (Russia)	Guskov et al., 1997
Twice higher (36%; 17%; $p < 0,01$)	270 children of liquidators compared with 540 children of unirradiated parents (The Rostov Region, Russia)	Amelina et al., 1998
The most part of big CM – cardiovascular system and CNS (at unirradiated – bone and muscular and cardiovascular systems)		
2,7 times higher (respectively, 142 ± 22 and 52,5 ± 12,4 for 1000)	253 children of liquidators of 1986 – 1987 compared with children of unirradiated parents (Russia)	Ermalitskiy et al., 2011
Reduction after 2001	Children of liquidators of Ukraine, 1987 – 2010	National Report of Ukr., 2011
Average frequency in 12 years (90,6 for 1000) it is reliable above. The maximum frequency in 1988 (117 on 1000 that is reliable above an average about the country – 91 for 1000)	Children of liquidators of Ukraine (13 136 people) for 1986 – 1998 compared with the children's population of the country	Stepanova et al., 1999, 2002 a, b;
More often deformation of throat, anomaly of tooth system, anomaly of hair-covering	Children of liquidators of Ukraine, 1987 – 2004 compared with other children	Horishna, 2005
Above all-Russian by 3,6 times; 47% have CM and genetic syndromes with prevalence of pathology of bone and muscular system	Newborns in families of the Russian liquidators, 1986 – 2003 (more than 30 thousand people) compared with newborns in the country (according to the Russian state medico-dosimetric register – RSMDR)	Sipyagina et al., 2006
Above all-Russian by 2,5 times (respectively, 5 866 and 2 362 on 100 000 children's population). Prevalence of CM of CNS at children of liquidators is higher, than at children in the polluted territories	Newborns in families of the Russian liquidators of 1986 – 2005 (more than 30 thousand people) compared with newborns in the country, and compared with newborns in territories polluted on ^{137}Cs at the level of ≥ 37 kBq/m^2 (according to RSMDR)	Zotova, 2007

Table 5. (Continued)

Frequency of CM	Group of newborns	Author
1,2 times higher, including: spina bifida – by 3,2 times, an anencephalia – by 3,1 times, cleft lip and palate – 1,7 times, reducing defects of extremities – by 1,6 times; by 2,1 times more often delay of pre-natal development	Children of liquidators, 1991 – 1999 (270 people) compared with 540 children of unirradiated parents (The Rostov region, Russia)	Lyaginskaya et al., 2009
Higher the frequency of microanomalies in a structure of heart, the big isolated defects of CNS	Children of liquidators, 1991 – 1999 (270 people) compared with 540 children of unirradiated parents (The Rostov region, Russia)	Kryinochkina, 2000
1,5 – 2,5 times higher	Children of liquidators, compared with children of personnel of the Kalinin and Smolensk NPP, 1987 – 2000	Ermalitskiy et al., 2013
Essential growth	Children of liquidators of Obninsk (Kaluga region, Russia), 1994 – 2002	Tsyb et al., 2004
Growth by 4 times	Children of liquidators of the Bryansk region	Matveenko et al., 2005

At Figure 1 data on dynamics of frequencies of nine CM of the strict account are provided on the 17 radioactive polluted regions of Belarus and 30 less radioactive territories of Belarus during 1981 – 2004. The radioactivity was determined by ^{137}Cs at the level ≥ 185 kBq/m^2 and ≤ 37 kBq/m^2 (National report. Belarus, 2006).

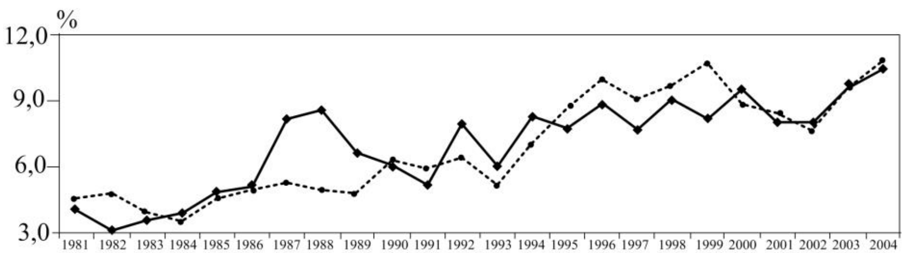

Figure 1. Dynamics of frequency (on 1000 childbirth) of nine CM of the strict account

Detailed data on dynamics of frequencies of some CM before Accident, in the first three years after Accident and in 5 – 18 years after Accident in 17 more polluted on ^{137}Cs ($\geq$ 185 kBq/m^2, circles, the line) and 30 less polluted ($\leq$ 37 kBq/m^2, small squares, dotted line) administrative regions of Belarus are given in Figure 2 (National report of Belarus, 2006).

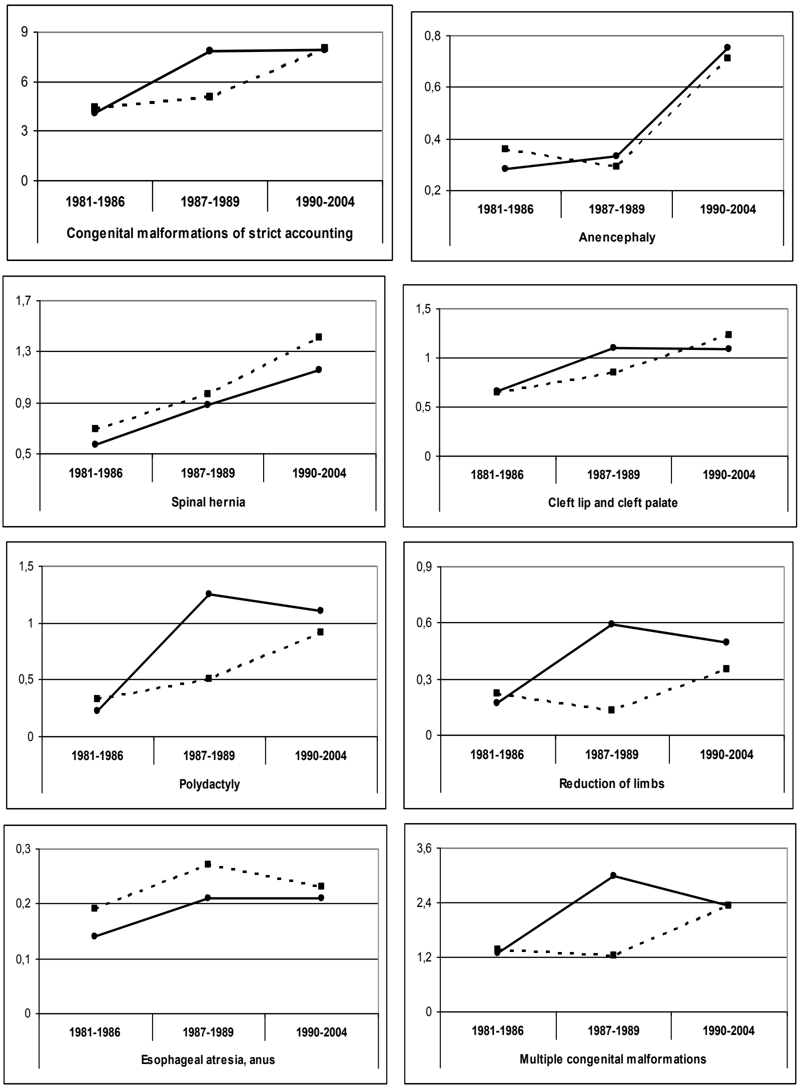

Figure 2. Dynamics of frequency (on 1000 childbirth) of CM of strict account.

Occurrence of CM of bone and muscular system in 1229 settlements of Belarus and Russia grouped in four groups on the level of radioactive pollution is presented at Figure 3.

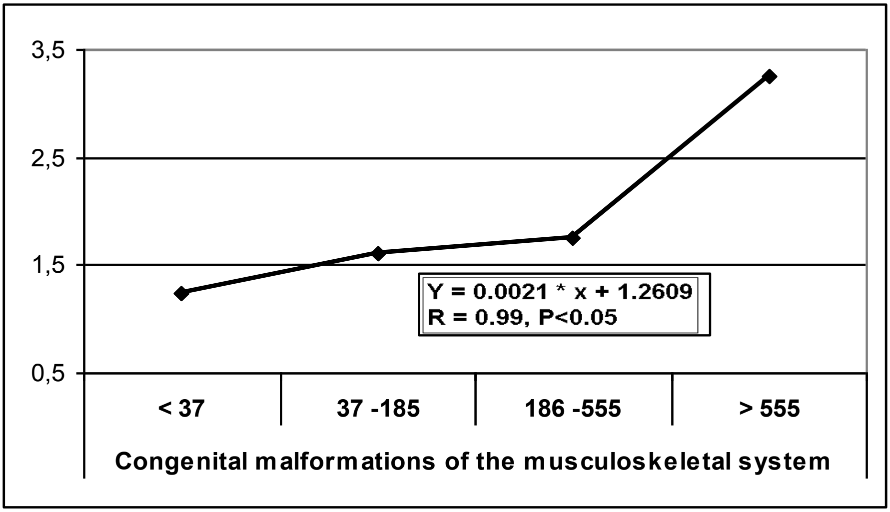

Figure 3. Frequency (on 1000 childbirth) of CM of bone and muscular system (the isolated polydactyly, reducing defects of extremities, system skeletal dysplasias).

Data are submitted depending on pollution level of ^{137}Cs of the place of residence in 1229 settlements of the Gomel and Mogilev regions of Belarus grouped in groups < 37 kBq/m^2, 37 – 185 kBq/m^2, 186 – 555 kBq/m^2, > 555 kBq/m^2, 1997 – 1999 (Zatsepin et al., 2007).

At Figure 4 data on total dynamics of all CM are submitted in the most radioactive polluted region of the Russian Federation – the Bryansk region. Data are shown at the polluted southwest territories (SWT) compared with data on all area (together with SWT) and with the least radioactive polluted area, 1991 – 2014.

At Figure 5 data of average frequencies of CM in four years in the most polluted SWT of the Bryansk region compared with less polluted regions are submitted.

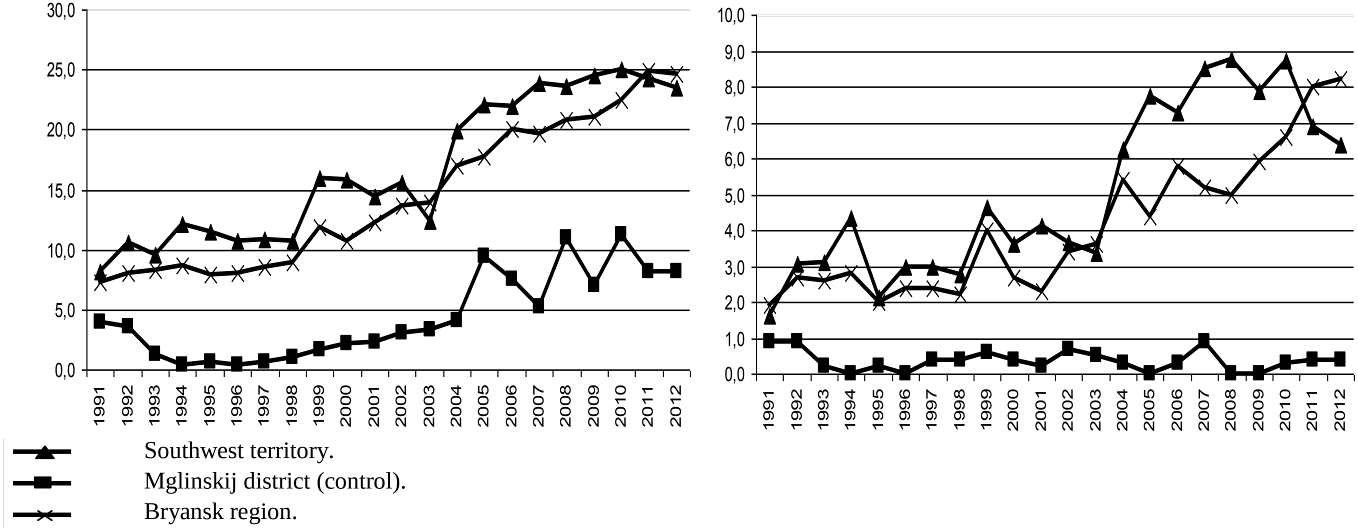

Figure 4. Dynamics of the general (at the left) and primary incidence (on the right) (on 1000 children's population) of CM of the children's population of the Bryansk region for 1991 – 2012 (Korsakov et al., 2014).

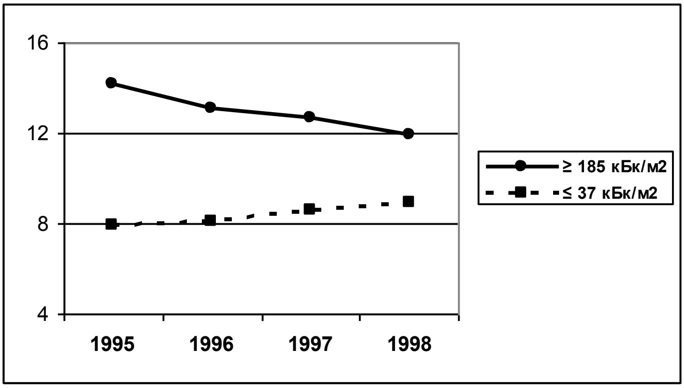

Figure 5. The general incidence (on 1000 live-born) of CM of the strict account of the Bryansk Region in 1995 – 1998 on the radioactive polluted by ^{137}Cs at the level ≥185 kBq/m^2 compared with less polluted (Fetisov, 1999).

At Figure 6 data are submitted on dynamics of five-year average values of frequency of the general incidence of CM of the strict account for the five years before and twenty years after the Accident. Radioactive pollution on ^{137}Cs at the level ≥ 185 kBq/m^2 in Barabinsk region and Zhizdrinsky district of the Kaluga region of Russia polluted at the level < 37 kBq/m^2 (Omaraskhabov, 2007).

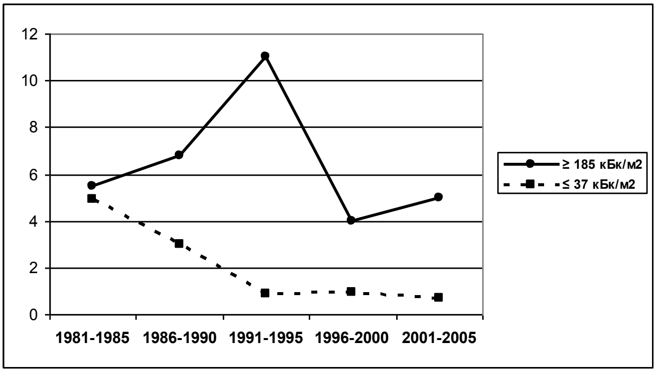

Figure 6. Dynamics of the general incidence of CM of the strict account (on 1000 children's population).

At Figure 7 it is shown the dynamics of frequencies of CM of heart and a skeleton in the most radioactive polluted territory of Germany-Bavaria for three years before and after the Accident.

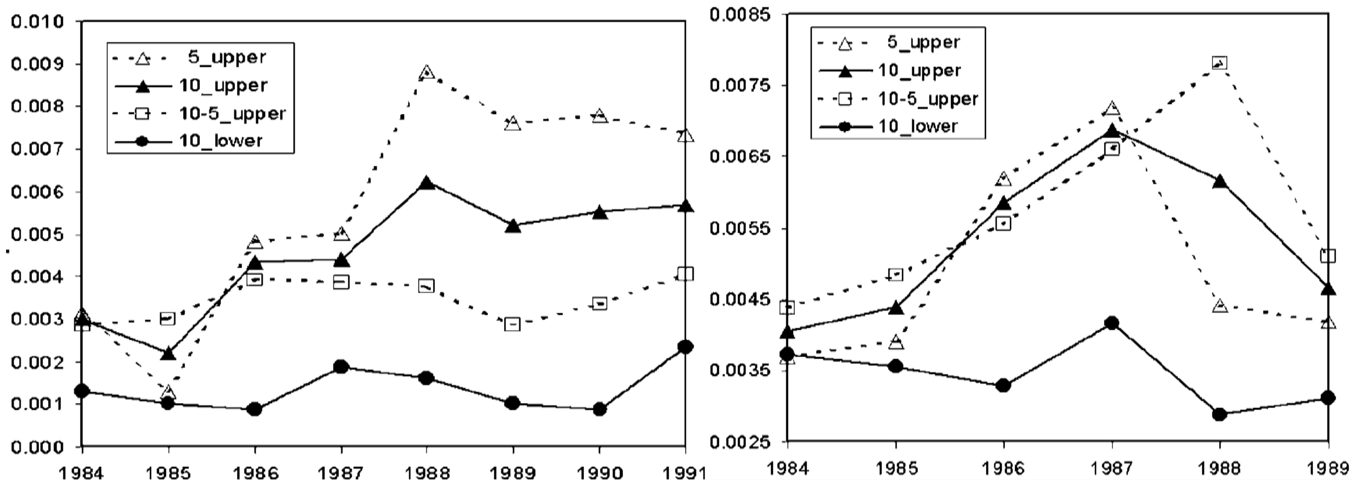

Figure 7. Primary incidence (%) of CM

Data are submitted among 10 radioactive polluted by ^{137}Cs on average at the level of 37,2 kBq/m^2 of territories of Bavaria (triangles) and 10 polluted at the level of on average 4,5 kBq/m^2 (black points): at the left – CM of cardiac, n = 2797), on the right – CM of deformations of a skeleton (n = 3686), 1984 – 1989. A dotted line – confidential 95% interval (Scherb, Wiegelt, 2003).

On the following two schedules data of monthly dynamics of frequency of a Down syndrome in Belarus (Figure 8) and the Western Berlin (Figure 9) are submitted.

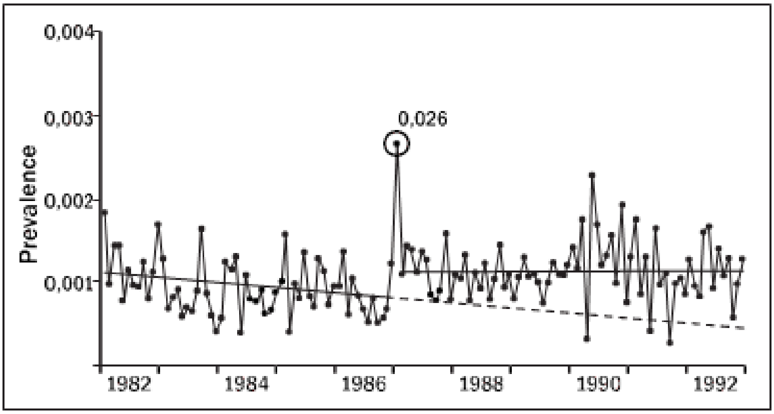

Figure 8. Occurrence of a Down syndrome in Belarus during 1982 – 1992.

Sharp rise in January, 1987 with the subsequent transition to the raised long-term trend is visible (Sperling et al., 2008)

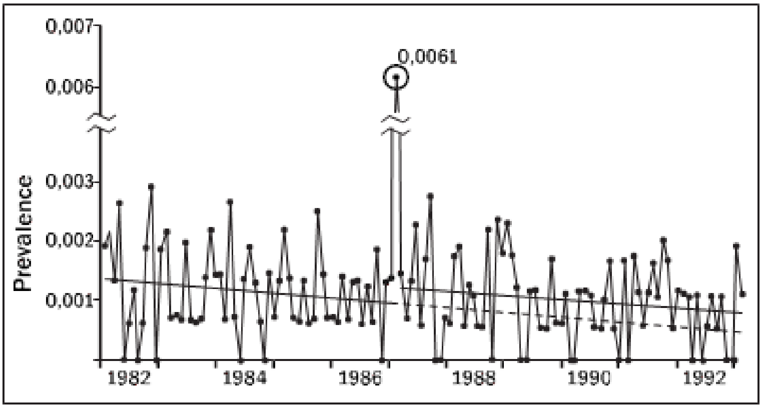

Figure 9. Occurrence of a Down syndrome in Western Berlin during 1982 – 1992.

Sharp rise in frequency in January, 1987, with the subsequent transition to the raised long-term trend is visible (Sperling et al., 2008).

At Figure 10 dynamics data on CM of strict account at fathers liquidators of 1986 – 1987 in Ukraine in ten years after Accident, and in picture 11 – data on CM of nervous system at children of the Russian liquidators (compared with similar indicators for the children living on the radioactive polluted territories) are submitted.

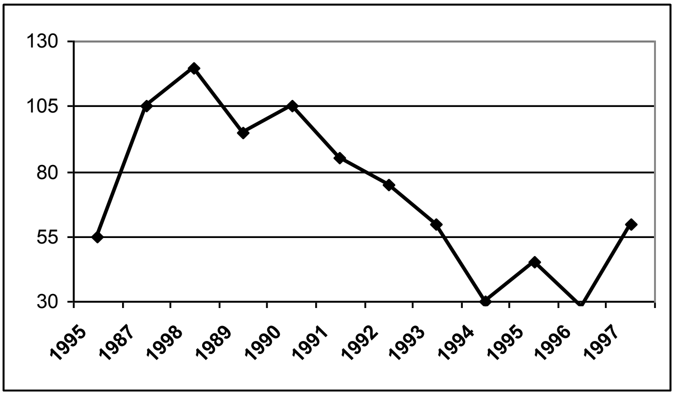

Figure 10. Frequency (per year of birth, on 1000 childbirth) of CM of strict account in families of the Ukrainian liquidators, 1987 – 1997. (National report. of Ukr., 2011). Data for 1995 – averages about the country.

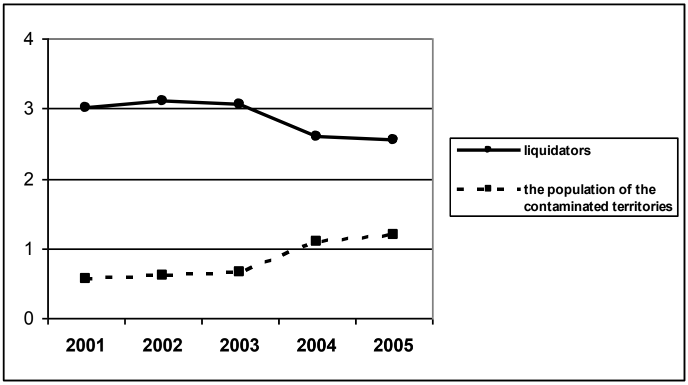

Figure 11. Dynamics of the general incidence (on 1000 children's population) of CM of nervous system at children of the Russian liquidators and at children in territories polluted by ^{137}Cs at the level of ≥ 37 kBq/m^2 (by data RSMDR, Zotov, 2007)

DISCUSSION OF RESULTS

More than 6000 genetically caused anomalies of development of the person are known (McKusick, 1998). Each healthy newborn has 3 – 5 such anomalies. Besides small anomalies, large congenital malformations (CM) are met. Their main reasons are genetic and ecological (including influence of pollution of the environment, food habits, an infection, and so on.) factors. Genetic factors (violation of codes of hereditary information) are also subjected to the influence of the genotoxic (chemical and physical) environment factors and many ecological factors are teratogenny. Therefore CM can be considered as indicators of influence of adverse factors of environment (Bochkov et al., 1989, 2001). There are 4 types of violations of the structure and functions of a fetus leading to CM: on the stages of zygote (gametopathy), blastula (blastopathy), an embriopathy (which have arisen during the period from 15 days to eighth week of an embryonal development) and the fetopathy (which have arisen after the tenth week of an embryonal development). The international classification of congenital anomalies and chromosomal violations is based on the anatomico-physiological principle and includes 12 groups of CM (class XVII ICD-10). The European register of CM (EUROCAT) considers 85 different CM. The medical statistics of Belarus, Ukraine and Russia considers only 21 CM of the strict account.

We must have in mind rather low level of detectability of CM even in the developed countries. The European register of CM (EUROCAT Registry, 1988) covered by 2000 only about 10% of all population of Europe (Hoffmann, 2001). But also in the countries having registers of CM remained not taking into sufficient account in the first years after Accident to 30% of small CM and to 20% of cases of a Down syndrome (Czeizel et al., 1991; Dolk, Lechat, 1993). In the majority of the European countries the statistics doesn't fix prenatal discovered CM which lead to the compulsory abortions (to Hoffmann, 2001). Therefore a picture of distribution and dynamics of CM at the radioactive polluted territories which is reflected in the publications based on official statistical data – is only “iceberg top” of possible embryotoxic influence of the additional radiation exposure caused by the Chernobyl accident.

There is a number of other reasons complicating drawing up a full picture of embryotoxic influence of the Chernobyl accident, among which:

- impossibility of the accounting of effect of all radionuclides; only a level of chronic low-level radiation by ^{137}Cs is practically taken into account, and the level of repeatedly bigger radiation during “the iodic period” isn't taken into account (the first several months after Accident), as well as possible effect of strontium-90, plutonium 239, 240 and americium-241;

- disadvantages of statistics of the accounting of CM during the period to and in the first years after Accident in Ukraine and Russia (the national register of large CM since the beginning of the 80th is only in Belarus);
- impossibility of the accounting of effect of migration (possibly, about 10% of women of childbearing age migrated from the strongly radioactive polluted territories of Ukraine and Russia (to 30% - in Belarus), in the first years after Accident (Yablokov et al., 2011, 2016).

The first of the listed above reasons complicates identification of communication between the level of pollution and occurrence of CM, the third reason leads to understating of frequency of the radiogenic CM revealed by statistics.

After the Accident the effect of screening (more careful medical examination) could influence statistics of CM. However this effect can't explain growth of occurrence of CM on the radioactive polluted territories for many years. For example, concerning large CM in Belarus the effect of screening isn't shown (Zatsepin et al., 2007) – all such CM were noted also earlier by the state statistics.

Besides, at the analysis of CM dynamics it is necessary to consider the accounting of a long-term trend of some increase of frequency of CM irrespective of the Chernobyl accident and the pollution of all biosphere connected, apparently, with increase by global pollutants. The Chernobyl radioactive pollution was imposed on the chemical pollution existing earlier in a number of regions. For example, in the Bryansk region there are territories of the combined radiochemical pollution (Korsakov et al., 2012). It is difficult to separate teratogenny influence of pesticides or emissions of cement works from the same influence of the Chernobyl radionuclides.

In the analysis of data on frequencies of CM it must be kept in mind also effect of artificial interruption of pregnancy. So, for example, in Belarus on a state program of interruption of pregnancy on medical and genetic indicators since 1992 (500 – 600 cases annually), it was succeeded to stabilize the frequency of the birth of children with CM (Lazyuk et al., 1996). Such purposeful programs don't exist in Ukraine and Russia, but the number of abortions on medical and genetic indicators, apparently, has significantly grown also in these countries. The number of such abortions is four times higher in the most radioactive polluted Bryansk region , than in the country in general – respectively, 5,8% and 1,4% (Motherhood, 2014).

Now we will pass to the analysis of the concrete data given above. WHO and IAEA consider (Chernobyl Joint News Release, 2005, IAEA 2006) that levels of the radioactive pollution caused by the Chernobyl accident is too low to cause the noticeable growth of CM. The review of the published works has shown that there is growth of CM among the newborns conceived in the first days and weeks after Accident and following years. They are: the Down syndrome, the anencephalia, the polydactyly, reducing defects of extremities and multiple CM, and also CM of CNS (Harjuletho et al., 1991; Ericson, Kallen 1994; Orlov, 1995; Akar et al., 1988; Korblein, 2000, 2002; Lazyuk et al., 1996, 1997, 1999, 2004; Naumchik et al., 2001; Hoffman, 2001; Kulakov et al., 2001; Yakovleva et al., 2003; Zatsepin et al., 2007; Sperling et al., 2001; Dancause et al., 2010; Wertelecki et al., 2010, 2014, 2016). Tens of works describe reliable growth of all CM totally (Stepanova, 1999; Fetisov et al., 1999; Ivanov et al., 2002; Tsyb et al., 2006; Korsakov et al., 2014) in several years after the Accident. One of the most convincing long-term factor is given in Figure 1. It belongs to the regions of Belarus with different extent of radioactive pollution. Data show: in 1987 CM frequency in more radioactive polluted territories has increased twice and remained at much higher level, than in less polluted areas within two years.

A sharp growth of number of CM in families of liquidators is obvious in the first several years after the Accident (Stepanova, 1999; Sipyagina et al., 2006, Zotova, 2007, Lyaginskaya et al., 2009; Ermalitsky et al., 2013, see Figure 10, 11, Table 12 app.).

Reliable confirmation of the increased CM level after Accident is data on the disability and structure of infantile mortality. Children's disability because of CM has increased in Ukraine more than three times from 1992 – 1993 to 2000 – 2001 (respectively, 10 and 31 on 10 000) (UNISEF, 2005). In structure of the reasons of child mortality in the radiation polluted SWT of the Bryansk Region in 15 years after the Chernobyl accident the role of CM has increased twice (Ivanov et al., 2002). In structure of the reasons of infantile mortality the specific weight of CM of the strict account has almost five times exceeded average value of this indicator across Russia (Zhilenko et al., 1999). There are data on growth of frequency of spontaneous abortions (abortus) and still births in families of liquidators (Ermalitsky et al., 2013). Reliable increase (from 4 to 50%) in the level of spontaneous abortions (abortus) and still births in the second half of 1986 – 1987 is described. It belongs to the radioactive territories of Austria, Great Britain, Norway polluted as a result of the Chernobyl accident, Poland, Latvia, Hungary, Germany, Croatia, Italy, Greece, Sweden, Finland, Iceland, Denmark, Switzerland, Russia, Ukraine (see reviews: Auvinen et al., 2001; Korblein, 2003, 2006, 2016; Frentzel-Beyme, Scherb, 2007; Serdyuk et al., 2004; Timchenko et al., 2014; Busby et al., 2009, 2016; Yablokov et al., 2011, 2016). In Figures 12 – 14 and Table 13 app. the examples showing the scale and prevalence of failures of pregnancy are also given. As CM are one of the important reasons of still births and abortions, so the increase in number of such failures of pregnancy leads to decrease in number of CM at newborns.

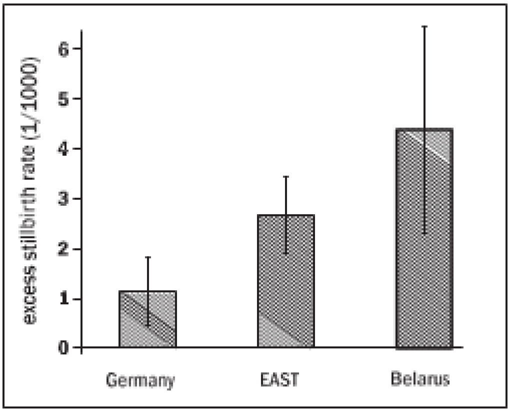

Figure 12. Increase in number of (the average size and standard mistake, on 1000 newborns) stillbirths in 1987 in comparison with average long-term value in Belarus, totally in Greece, Hungary, Poland, Sweden (“EAST”) and in Germany (Korblein, 2003).

Increase in number of abortions and stillbirths, happening on the stronger radioactive polluted territories, can explain, at first sight paradoxical, decrease in frequency of CM on more radioactive polluted territories compared with what is observed on poorly polluted. For example, occurrence of CM is higher in Klintsy and Klimovskiy districts of the Bryansk Region (Korsakov et al., 2014; see table 10 app.) at the smaller average density of pollution of these territories by ^{137}Cs and ^{90}Sr concerning other SWT. The cause of such situation can be:

- influence of not considered in official estimates of radioactive pollution by transuranium radionuclides or big radiation defeat in the period of “iodic blow” in the first months after Accident;
- appearing during pre-natal development of bigger number of the large CM incompatible with continuation of development of an embryo and fetus, the eliminating at abortions and stillbirths (Korsakov et al., 2014).

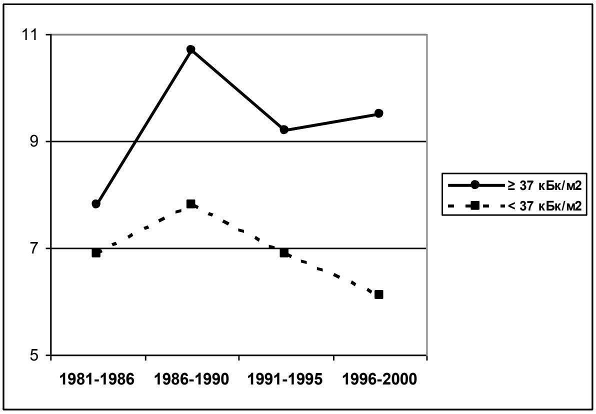

Figure 13. Dynamics of indicators of a stillbirths (on 1000 live-born) in the polluted districts of the Kaluga Region 1st period – 1981 – 1986; the 2nd period – 1986 – 1990; the 3rd period – 1991 – 1995; the 4th period – 1996 – 2000 (Tsyb et al., 2006).

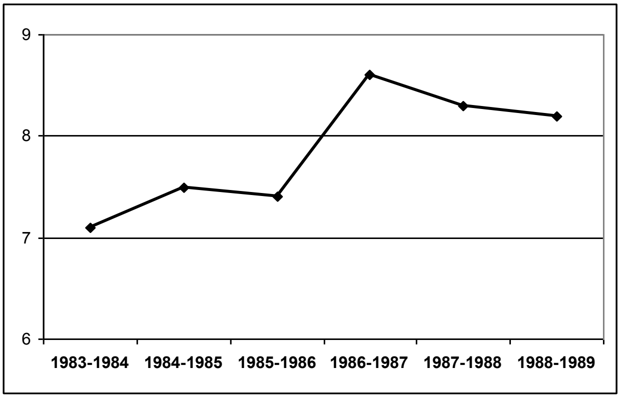

Figure 14. Average number of spontaneous abortions in three years before Accident (1983 – 1986) and three years after Accident (1986 – 1989) in Norway (Irgens et al., 1991)

The majority of large mutations leads to the termination of development of a fetus already at early stages (Nikitin, 2005). Therefore genetically caused CM found in newborns are those which weren't eliminated in process of gametes (sperm cells and egg cells), and then during natural selection among the impregnated ovum before and during implantation, and then in the course of the embryonal development.

Considering it, it is necessary to consider that increase in frequency of genetically caused CM at newborns has to reflect increase in tens (if not in hundreds) time of rate of mutational process at the level of gametes. That this process really happens on the radioactive polluted territories by the Chernobyl rainfall, testifies, including (Naumchik et al., 2001; Lazyuk et al., 1999; Zatsepin et al., 2007):

- increase in a share of abnormal sperm cells (Lazyuk et al., 1999);
- increase in frequency of prenatal mortality (Irgens et al., 1991; Golovko, 1994; Korblein, 2003; Tsyb et al., 2006) (see fig. 12 – 14 and table 13 app.);
- increase among share abortuses with CM determined by *de novo* mutations (Lazjuk et al., 1997; Lazyuk et al., 1999) (see table 4 app.);
- a bigger share of CM determined by *de novo* mutations on the more radioactive polluted territories (Zatsepin et al., 2007) (see fig. and table 13 app.)

Significantly different dynamics of frequencies of some CM on more or less radioactive polluted territories (see fig. 2 and tab. 1 – 4 app.) it can be connected with various nature of different CM (genetic, ecological, time of appearance et al.). Some of CM are expression of mutations, every time newly arising in population – *de novo* mutations. Mutations of *de novo* aren't inherited, arise at conception and define emergence of such CM as a polydactyly, reducing defects of extremities and multiple CM. These CM are more often met in territories with density pollution of ^{137}Cs more than 555 kBq/m^2 (Lazjuk et al., 1997; Lazyuk et al., 1999, 2004; Naumchik et al., 2001, Zatsepin et al., 2007).

The theoretical objection of WHO experts and IAEA that the Chernobyl level of radiation is insufficient for calling CM and the statement that "*Small, but steady increase in messages on congenital defects ... belongs to the better statistics, not radiation*" (IAEA, 2006), are obviously wrong or for the reason that real cumulative doses of radiation are significantly higher, than calculated (for example, for the account, considerable radiation in the period of "iodic blow”). The second reason is even such low levels of chronic radiation cause big effects, than it is supposed officially working models of radiation risk of UNSCEAR and ICRP.

Main reason, why WHO, IAEA, UNSCEAR experts (Dolk, Nochols, 1999; ICRP, 2003, 2007; NCRP, 2013 and many other) don't recognize existence of connection of growth of frequency of CM with additional radiation exposure after the Chernobyl accident, is a lack of correlation between the CM level and size of the received dose. At the same time the population dose of radiation is determined, as a rule, not on the basis of averaging of direct measurements of content of radionuclides in the organism and by means of biodosimetry (by changes in the structures registering radiation – chromosomes, tooth enamel). It is defined by the volume of the products eaten by the conditional average person with the average levels of pollution of each products, by the time spent of such average conditional person outdoors. The size of consumption of products, their range, and features of individual behavior are generalized on the basis of polls of small part of the population during which people are offered to remember what they drank and ate where they went months and years ago. The estimates of average virtual doses of radiation received as a result of such doubtful calculations are compared to quite concrete data on levels of meetings of CM. From the methodological point of view, such comparison isn't reliable, and can't form a basis for determination of correlation of incidence of CM with the received radiation. The comparison of the CM level to the level of the general radiation pollution of the place of full-time residence is more objective. Such comparisons are carried out a lot (only their small part is given in the present article), and, mostly, they show positive correlation.

Conclusion that *“scientific information available so far doesn't show any influence of radiation exposure on pregnant women”* (Little, 1993; Gastronovo, 1999, NCRP, 2013 et al.) contradicts many publications on occurrence of CM on radioactive polluted territories of Belarus, Ukraine and Russia compared with a near located not polluted radioactive territories. This radiogenic increase in occurrence of CM is confirmed even officially – the state reports on Accident consequences in Belarus and Ukraine, say nothing of all western scientific protocols fulfilled with observance researches (Dancause et al., 2010; Wertelecki, 2010, 2014, 2016; Yevtushok et al., 2013 and others) which have in details analysed the situation with CM distribution in one of the most radioactive polluted areas of Ukraine – Rovnya. Denial of communication of sharp increase in 1987 of the level of meetings of the Down syndrome, as well as the subsequent increase in occurrence of other CM on more radioactive polluted territories, would be somehow more proved if for these observed effects any other explanations were offered.

The fact of change of a range of CM pays attention on the radioactive polluted territories compared with others: on the radioactive polluted territories CM of bone system prevail (including reducing defects of extremities and multiple CM) whereas on the radioactive “pure” territories CM of cardiovascular system prevail.

Among the materials given above there are some supervision which aren't finding explanations yet. Among such, for example, reduction (but not growth) of the Down syndrome frequencies on the radioactive polluted territories of Norway (Terje Lie et al., 1992), or growth of frequencies first of all not CNS and bone and muscular system (as in the majority of the described publications), and CM of cardiovascular system and other organs (Amelina et al., 1998; Krynochkina, 2000; Horishna, 2005). In the last cases either small selection, or the directed attention of researchers only to one of CM groups can be the cause of such difference from the general trends.

By calculations, the Chernobyl radioactive pollution has led to appearance only in Bavaria for the first five years after Accident of 1000 – 3000 additional cases of CM (Scherb, Weigelt, 2010). In Belarus total number of newborns with CM of the strict account reached annually 2500 (Lazyuk et al., 1996). Extrapolating such data, it is possible to assume that in the territories polluted at the level of $\geq$ 37 kBq/m^2 there could be about 10 – 13 thousand newborns with large CM annually in the first fifth anniversary after Accident, about 6 – 8 thousand in the second fifth anniversary, about 3 – 5 thousand annually – in the second decade after Accident, and on 2 – 3 thousand – in the subsequent the fifth anniversary. For 30 years which have passed since 1986 total number of such innocently affected by Accident can make 140 – 170 thousand people. Many years more annually among the born newborns in Europe several thousands will bear the congenital malformations caused by the Chernobyl radiation.

The increasing attention of researchers of consequences of embryotoxic influence of additional Chernobyl radiation is drawn by a problem of small anomalies of development. These small anomalies which occur practically at each child aren't considered by the medical statistics. More and more data is collected (Kruslin et al., 1998 et al.; Stepanova et al., 2002; Demenkova et al., 2011) that at children of liquidators and children on the radioactive polluted territories is formed a bit different phenotype – with multiple small anomalies of development.

Increase in number of CM on the radioactive polluted territories does the assumption of the radiogenic nature of increase of meetings of CM after Accident quite reasonable according to Bradford Hill’s canons.

CONCLUSION

Despite disadvantages of medical statistics, it is necessary to recognize that growth of number of newborns with CM accompanied the Chernobyl radioactive pollution not only in Belarus, Ukraine and the European part of Russia, but also in other countries of Europe.

Refusal of official medicine of recognition of communication of this increase with the Chernobyl pollution is caused by methodologically incorrect comparison of frequency of CM with always inexact definition of an effective dose based on polling (but not on physically measured) data.

Total frequency of all large CM has sharply increased in the first years after Accident and then for 10 years gradually decreases. Dynamics of change of frequency of different CM is various. The analysis of frequencies of separate CM, but not their sums is necessary for more in-depth study.

The reduction of frequency of CM found in a number of researches on the more radioactive polluted territories (Kapustina, 2005; Korsakov et al., 2014), apparently, is connected with the raised elimination of large CM in the course of prenatal development (increase in number of abortions and stillbirths).

On more radioactive polluted territories, and among posterity of liquidators, the phenotype with a large number of small anomalies of development which aren't considered by medical statistics is formed.

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Appendix

Table 1. The general frequency (on 1000 childbirth) of CM of the strict account in 17 more radioactive polluted on ^{137}Cs (≥ 185 kBq/m²) and 30 less polluted (≤ 37 kBq/m²) in 1986 administrative regions of Belarus, 1981 – 2004 (National report of Belarus, 2006)

Density of radioactive pollution in 1986	1981 – 1986	1987 – 1988	1990 – 2004
> 185 kBq/m²	4,08	7,82**	7,88**
< 37 kBq/m²	4,36	4,99*	8,00**

* P < 0,05; ** P < 0,01.

Table 2. Frequency (on 1000 childbirth) of CM of the strict account in 17 more radioactive polluted (≥ 185 kBq/m², the top line) and 30 less polluted (≤37 kBq/m², the lower line) in 1986 administrative regions of Belarus, 1981 – 2004 (National report Belarus, 2006)

Kinds of CM	1981 – 1986	1987 – 1989	1990 – 2004
anencephalia	0,28	0,33	**0,75**
	0,36	0,29	0,71
myelocele	0,57	0,88	1,15
	0,69	0,96	**1,41**
cleft lip and palate	0,65	1,09	1,08
	0,64	0,84	**1,23**
polydactyly	0,22	**1,25***	1,10
	0,32	0,50	0,91
reduction of extremities	0,17	**0,59***	0,49
	0,22	0,13	0,35
esophageal atresia and atresia of anus	0,14	0,21	0,21
	0,19	**0,27**	0,23
multiply CM	1,27	**2,97***	2,31
	1,35	1,23	2,32

* P < 0,01 in comparison with 1981–1986.

Table 3. Frequency (on 1000 childbirth) of CM of the strict account in 17 more radioactive polluted (>185 kBq/m^2) and 30 less polluted (<37 kBq/m^2) in 1986 administrative regions of Belarus, 1981 – 2006 (Zatsepin et al., 2007)

Kinds of CM	More polluted areas			Less polluted areas		
	1981 – 1986	1987 – 1989	1990 – 2006	1981 – 1986	1987 – 1989	1990 – 2006
Frequency of CM	4,1	7,8*	8,2	4,3	5,0	8,1
anencephalia	0,3	0,3	0,8	0,4	0,3	0,7
myelocele	0,6	0,9	1,2	0,7	0,9	1,4
cleft lip and palate	0,6	1,1	1,1	0,6	0,8	1,2
polydactyly	0,2	1,2*	1,2	0,3	0,5	0,9
Reduction defects of extremities	0,2	0,6*	0,5	0,2	0,1	0,3
atresia/stenosis of gullet/anus	0,1	0,2	0,2	0,2	0,3	0,3
multiply CM	1,3	3,0*	2,5	1,3	1,2	2,4
the Down syndrome	0,9	0,6	1,1	0,6	0,9	1,1

* P < 0,01.

Table 4. Frequency (for 1000) of CM of the strict account at medical abortuses and fetus in Minsk and polluted >555 kBq/km^2 territories of the Gomel and Mogilev regions (Lazyuk et al., 1999 a, b)

Kinds of CM	Minsk		Polluted territories
	1980 – 1985 (n = 10 168)	1986* – 1996 (n = 20 507)	1986* – 1995 (n = 2 701)
General frequency of CM (%)	5,60	4,90	7,21 **
Anomalies of CNS	0,32	0,53	0,54
Polydactyly	0,63	0,53	0,79
Multiple defects of extremities	0,07	0,10	0,28

* The second half of the year; ** P < 0,05.

Table 5. Occurrence of cases of the Down syndrome among given rise in Belarus in January, 1987 (Lazyuk et al., 2002)

Towns and regions of Belarus	Occurrence of CM (for 1000)		H	O	H/O	95% CI
	January 1987	1981 – 1989				
All Belarus	2,5	1,0	31	13,9	2,2	1,5 – 3,2
Gomel region	3,6	1,1	8	2,6	3,1	1,4 – 6,2
Minsk region	3,1	1,1	6	2,2	2,8	1,1 – 6,0
Minsk	2,7	1,1	6	2,6	2,3	0,9 – 5,1
Vitebsk region	2,2	1,0	4	1,8	2,1	0,6 – 5,7
Grodno region	1,7	0,9	3	1,6	1,9	0,2 – 4,6
Mogilev region	1,2	0,9	2	1,5	1,3	0,2 – 4,9
Brest region	1,0	0,8	2	1,8	1,1	0,1 – 4,0

H – observed number of cases; O – the expected number of cases; CI – a confidential interval.

Table 6. Occurrence (on 1000) of the Down syndrome in 17 strong and 30 less radioactive administrative regions of Belarus polluted on ^{137}Cs (National report. Belarus, 2006)

Density of radioactive pollution in 1986	1987 – 1988	1990 – 2004
>185 kBq/km^2	0,59	1,01
<37 kBq/km^2	0,88	1,08

Table 7. Average occurrence (on 10 000 live-born) some large CM on radioactive polluted territories of Ukraine (The Rivne and Khmelnytskyi regions) compared with Central European (data of EUROCAT) in 18 - 22 years after Accident (Dancause et al., 2010)

Kinds of CM	Europe 2004 – 2007	Ukraine[1] 2005 – 2008	
Defects of nervous tube	10,2	18,5*	81%
Anencefalia and close CM	3,8	8,1*	213%
Microcefalia	2,3	6,0*	261%
Anophthalmia – microphthalmia	1,4	2,3*	64%
Congenital cataract	1,0	2,2*	220%
“Harelip”	9,6	10,6	10%

[1] Rivne and Khmelnytsky regions; * P < 0,01.

Table 8. Primary incidence (on 10 000 live-born) of some CM on more (Polissia) and less radioactive polluted territories of the Rivne Region, 2000 – 2009 (Yevtushok et al., 2013, Wertelecki et al., 2014a)

Kinds of CM	Polissia	Other regions	Polissia,%
microphthalmia	2,5*	0,8	312
Microcefalia	6,1*	3,3	85
Spinal Bifida	14,1*	8,2	72
Defects of nervous tube	26,1*	16,4	59
Anencefalia	5,1	4,0	28
the Down syndrome	15,9	14,3	11
All CM of strict account	41,0*	29,0	41

* $P < 0{,}001$.

Table 9. The general incidence (on 1000 live-born) CM of the Bryansk Region in 1995 – 1998 on radioactive polluted by ^{137}Cs at the level of ≥185 kBq/m^2 compared with less polluted (Fetisov, 1999)

Territories of region	1995	1996	1997	1998	1995 – 1998
≥185 kBq/m^2	14,2	13,1	12,7	11,9	13,0
≤37 kBq/m^2	7,9	8,1	8,6	8,9	8,4

Table 10. Levels of the general and primary incidence of children of CM (on 1 000 children's population), on SWT of the Bryansk region during 1991 – 2012, and average density of pollution of areas by ^{137}Cs and ^{90}Sr (Korsakov et al., 2014)

Territories	Density of pollution		the incidence of disease, M ± m	
	^{137}Cs	^{90}Sr	general	primary
Krasnogorsky district	**572,8**	**26,3**	12,2 ± 1,0	2,2 ± 0,4
Zlynkovsky district	**570,9**	**42,5**	10,8 ± 1,4	2,3 ± 0,5
Novozybkovsky district	**565,0**	**17,4**	13,9 ± 1,1	4,9 ± 0,5
Gordeevsky district	383,3	9,2	11,9 ± 1,7	3,9 ± 1,0
Klintsy district	260,5	6,7	**33,7 ± 3,2**	**11,0 ± 1,5**
Klintsy	229,0	6,7	15,5 ± 1,5	4,9 ± 0,7
Klimovsky district	175,7	7,8	**23,4 ± 1,9**	**8,0 ± 0,7**
Starodubsky district	68,4	2,3	12,1 ± 1,3	3,0 ± 0,5

Table 11. Occurrence (on 1000 childbirth) CM of the central nervous system in Turkey before Accident (according to different authors from Schmitz-Feuerhake, 2006)

Territory	Before	After
Bursa	5.8[1]	20.0[2], 12.6[3], 6.3[4]
Trabson	2.12[5]	4.39[6]
Elazig	1.7[7]	2.2 – 12.5[8], 10.0[9]

[1]1983 – 1986; [2] January – June 1987; [3] July – December 1987; [4] January – June 1988; [5] 1981 – 1986; [6] 1987 – October 1989; [7] 1985 – 1986; [8]1987 – 1988; [9]1989.

Table 12. Frequency of CM and other violations of development of fetus in families of liquidators of 1986 – 1987, of fathers of personnel of the Smolensk NPP and the Ryazan region in 1987 – 2000 (for 1000) (Ermalitsky et al., 2013)

Frequency of CM and other violations of development of a fetus	personnel of NPP (not liquidators) n = 547	Liquidators personnel of NPP n = 332	Liquidators of Ryazan region n = 253
CM frequency	82,7 ± 11,8	111 ± 17*	142 ± 22*
Delay of pre-natal development	83,7 ± 11,4	175 ± 17*	186 ± 25*
spontaneous abortions	72,3 ± 11,1	163 ± 14*	184 ± 22*
stillbirths	8,6 ± 4,3	9,2 ± 11,9	12,9 ± 6,4
early neonatal mortality	12,3 ± 5,1	15,3 ± 4,9	19,4 ± 7,8

* Distinctions are statistically reliable with group of personnel of the NPP, $p < 0{,}05$.

Table 13. Frequency of failures of pregnancies (number per 100 pregnancies, n = 2457) before Accident in territories of Mogilev (Belarus) and Bryansk areas (Russia) with the increased level of radioactive pollution on ^{137}Cs in 1987 – 1992 (Golovko, 1994)

Density of radioactive pollution by ^{137}Cs	1980 – 1985	1987 – 1992
≥37 kBq/m^2	9,6 ± 0,9	13,4 ± 1,0*
<37 kBq/m^2	4,8 ± 1,2	4,3 ± 0,4

* $P < 0{,}05$.

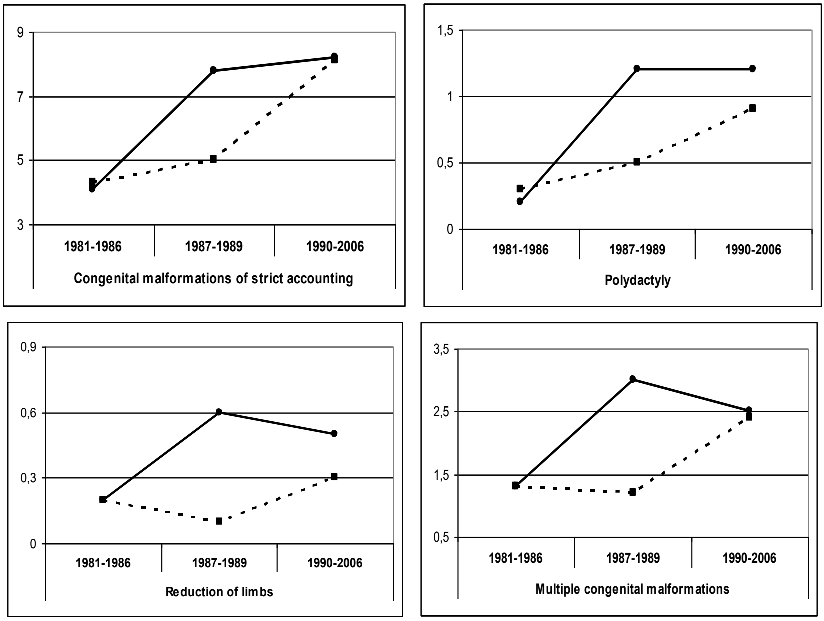

Figure A-1. Dynamics of frequency (on 1000 childbirth) of CM of strict account before Accident, in the first three years after Accident and in 5 – 20 years after Accident in 17 more polluted on ^{137}Cs (≥ 185 kBq/m^2, circles, the line) and 30 less (≤ 37 kBq/m^2, small squares, a dotted line) the administrative regions of Belarus polluted in 1986 (Zatsepin et al., 2007).

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Chapter 3

CHERNOBYL AND NEW KNOWLEDGE ABOUT THE IMPACT OF LOW DOSES OF RADIATION

E. B. Burlakova[1], A. M. Grodzinsky[2], K. H. Loganovsky[3], T. A. Mousseau[4], A. P. Moller[5], M. V. Naboka[6] and B. M. Shestopalov[6]

[1]Institute of Biochemical Physics, Russian Academy of Sciences, Moscow, Russia
[2]Institute of Cell Biology and Genetic Engineering of the National Academy of Sciences of Ukraine, Kiev, Ukraine
[3]State Institution "National Research Center for Radiation Medicine of National Academy of Medical Sciences", Kiev, Ukraine
[4]Department of Biological Sciences, University of South Carolina, Columbia, SC, US
[5]Laboratory of Ecology, Systematics and Evolution, Universite de Paris-Sud, Paris, France
[6]Radioecological Center of the National Academy of Sciences of Ukraine, Kiev, Ukraine

ABSTRACT

An international research team has analyzed their own studies and data available from the literature concerning the biological effects of chronic or acute exposure to ionizing radiation (IR) on humans and biota as a consequence of the Chernobyl accident. Mechanisms of their effects at the cellular, body, and population levels were studied and compared. It is shown that multiple somatic cell line diseases (primarily non-cancerous), which in subsequent generations lead to reduced adaptation, increased mortality and degeneration of the population, can be registered in all groups of biota including humans. Simultaneously, it is demonstrated that effects of low-dose chronic irradiation are expressed more significantly than those after one-time acute exposure of higher doses. Non-linearity of the dose-effect relationship is commonly reported as well. We also emphasize commonality in mechanisms of disease manifestations in many studied biological groups. Along with radiation-induced damage to DNA and genomic instability, attention is drawn to the fact, that most of the effects are not directly induced by radiation, but indirectly through regulation and through alterations in the immune and antioxidant status of the organism, which affects sensitivity to environmental factors. The response of the organism to low doses of IR is a complex function of not only dose, but of also its intensity, the time of exposure, and the time period that it takes to engage recovery (repair) systems.

INTRODUCTION

Problems of the impact of low-dose ionizing radiation on humans and biota have been reviewed by the International Commission on Radiation Protection (NCRP), the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the National Academy of Sciences of the USA, the French Academy of Sciences and others. Special programs were created in the EU - RISK-RAD, in the US Department of Energy, in the institutions of Japan and elsewhere. These problems have been dealt with by many researchers: A. Petkau, R. Bertel, J. Gofman, M. Goldman, J. Neel, H. Paretzke, B. Ulsh et al., in the CIS (USSR) - N.Timofeev-Resovskii, V. Baraboy, E. Burlakova, V. Glazko, D. Grodzinsky, N. Dubinin, A. Kravets, A. Kuzin, G. Polikarpov, D. Spitkovsky, V. Shevchenko, L. Endrus et al., many doctors from Belarus, Russia and Ukraine, dealing with the health of the population affected by the accident.

In the fields of nuclear medicine, radiobiology, and radioecologya considerablearray of knowledge has accumulated regarding the effects of high doses of ionizing radiation (IR) on cells, organs, organisms and populations of flora, fauna and humans. However, our understanding concerning the effects of low-dose radiation was until recently quite contradictory and insufficient to assess its impact. It should be emphasized that the analysis of the pre-Chernobyl data allowed individual researchers [1,2, and others] to report a high risk of low doses of IR to human health and the non-linear nature of the "dose - effect" relationship. The Chernobyl accident, which resulted in large populations and clean-up workers (a.k.a. the liquidators) to be exposed to relatively low doses, greatly raised concerns about this problem. Therefore, a number of independent research groups from different countries conducted studies of the accident. Studies on the radiation response of cells, multicellular organisms and ecosystems, which were affected by Chernobyl disaster, have revealed new, previously unknown to science, evidence and facts, as well disclosing new patterns of the manifestation of radiobiological reactions.

The term "low dose", which is often used in the literature, requires some clarification, since different authors refer to it ambiguously. If in the case that there is a dose-threshold for an effect, the small (or "low") doses will be their sub-threshold value. For example, in the development of radiation sickness, low doses are considered as those at which the medullary syndrome is not detected. In clinical practice such doses of IR are called "low" if no clinical effects are observed, which could indicate a manifestation of the deterministic effects of radiation. Such are the doses up to50cSv (500mSv or mGy).

If describing the stochastic effects of IR in cells, for which there is no threshold dose values, e.g., where the magnitude of acquired dose predicts the frequency of manifestation of the effect, rather its intensity, the concept of "low dose" is more complicated. This interval of low doses depends on the type of observed responses of cells or multicellular organisms to the action of radiation, as well as on a peculiar radioresistance of the body. It is well known that within major taxa of all the kingdoms of nature, the radioresistance of species varies by many orders of magnitude. Therefore, a lethal dose for some species may be "low" for others. A well-known example of a highly radioresistant species in animal kingdom are most insects in the adult stage, and in the plant kingdom there are some cyanophytes (*Hormogoniphyceae*) known to be capable of surviving under radiation at doses up to 10,000 Gy [3].

It could be possible, as an argument for setting a limit for low doses of IR, to make such a suggestion: low doses are to be considered as those at which molecular damage that is arising from exposure is completely eliminated by cellular repair systems. Indeed, if the repair of DNA or other radiosensitive targets was absolutely complete, we would understand the low dose of IR as being an interval within which the repair system fully eliminates all types of radiation damage in cells. However, repair is usually not perfect – despite DNA repair, some mismatch normally occurs, whereby, even at the slightest dose of radiation, elevated frequencies of radiation-related defects can be observed. Therefore, this approach cannot be used in establishing a threshold for low-dose IR, and usually some statistical approaches are applied to allocate the interval of low doses. In this case the range of low doses is limited to a maximum value of the dose, at which the radiation-induced effects on a certain quantitative parameter cannot be reliably identified for a population of cells or organisms (cohort). Some assessments of the frequency of occurrence of leukemia and solid cancers in humans show that the level of low doses for this effect is within 20-40 mSv. However, evaluation of the additive cancer frequency requires a much larger sample size, which is approximately inversely proportional to the square of the additive frequency of disease.

There are some difficulties in determining the range of low-dose related frequency of cancers due to the fact, that the radiation carcinogenesis for many forms of the disease has a very long latency period, and the cancer may occur decades after exposure. For such a long time the effects of radiation may be masked by some effects of other manifestations caused by environmental factors that might have radiomimetic properties. According to epidemiologists, with decreasing radiation dose, the degree of uncertainty of results increases to such an extent that it is difficult to identify whetheran actual effect of radiation has been manifested. However, this uncertainty does not give reason to conclude that there is an absolutely safe exposure. Because of this uncertainty, the principle of ALARA (as low as reasonably achievable) was formulated, according to which the maximum possible way to reduce the radiation doses hould be sought.

When selecting a limit to low doses to humans one must also take into account a handful of additional conditions that affect the radioresistance of the organism. In particular, it is necessary to account for age as radiosensitivity of the early developmental period of most organisms is usually significantly higher than for adults, which will undoubtedly influence the dose limit that can be considered as small. Radioresistance depends on nutrition too: a well-nourished individual may have a higher radioresistance abilities than in the case of individuals having a shortage of essential dietary fatty acids, amino acids, antioxidants and other substances, the presence of which increases the level of protective and regenerative processes of the body.

Radiobiological experiments conducted on laboratory animals, plants, bacteria, yeast, and cell cultures permit very large sample sizes for studies. For example, some radiobiomarkers, like the inversion in *Waxy* gene in pollen grains of barley, can easily provide a sample size of a billion. Hence, an important benefit of radiobiological studies using model systems is that one can minimize uncertainties in the assessment of low dose IR effects.

However, experiments in the laboratory and controlled environments may also bring about uncertainty. For example, the output level of spontaneous chromosomal aberrations may fluctuate to such extent that the averaged contribution to their generation as a response to exposure in a certain range of low doses may not be statistically significant. Of course, such a failure to prove the effect of radiation does not mean that such effects do not exist: their frequency is simply low and the sample size might not be large enough.

A very interesting idea about low doses of IR was expressed by DM Spitkovsky: a cell is considered as not exposed to radiation if the radiated target did not deposit any energy of IR (target hit has not occurred), so the minimum dose is the dose at which the cell undergoes one hit per target. The logic of this argument is impeccable, if one ignores the existence of the "bystander effect". However, if, on average, all cells were subject to a single hit, then the appropriate dosage would be B_o, which overall might hardly be considered small.

In the literature, the term "low dose" is often understood as quite a certain dose value, usually borrowed from the hygiene standards of radiation safety. Such hygienic dose limits are set by international organizations (ICRP, UNSCEAR to the UN and the IAEA). In establishing these dose limits, the epidemiological data as well as socio-psychological aspects of the possible impact of higher levels of exposure were taken into account. In accordance with the Radiation Safety Standards the dose limit is considered a value of no greater than 0.25 Sv. However, it should be noted that for a century, during which humans have dealt with sources of ionizing radiation, the dose limits that were considered safe for humans have sharply dropped several times. For example, at the time of Marie Curie's grand discoveries a so called "erythema dose" (dose which caused skin erythema) was adopted as safe. This dose is greater by two orders of magnitude than the current value of the permissible dose!

The problem of determining low doses in the case of chronic exposure is transformed into the problem of the "low power" of dose when it is necessary to take into account a cumulative dose, the relative biological effectiveness of chronic exposure and a number of other features of the body's response to chronic exposure.

There are two realistic definition of low doses of ionizing radiation. According to one of them, this dose is small, below which there is no possibility to detect the harmful effects on health. This level was set as the ICRP 20 rad or 200 mGy. However, many researchers believe that this level is significantly lower - up to 1 rad (10 mGy). Another definition of low doses of radiation is their identification with the natural background radioactivity [4]. However, the pattern varies greatly in different parts of the earth, so it is hardly possible to use it as a boundary limit of small doses. In areas with high levels of natural local population mainly consists of the descendants of those who lived for many generations in the conditions of high doses and for a longer period could happen selection for increased radioresistance (in VURS radioresistance of rodents increased in 60 years).

To summarize, the following can be noted:

1. Based on experiments and observations of numerous “dose-effect” curves, a limit of “low doses” of IR can be assumed as the value at which the studied effect is null or changes sign.
2. For deterministic (clinical) effects of low doses of radiation, the limit may be up to 500mSv for human; for plants the low doses limit may be higher.
3. In human epidemiological studies the detectable limit of low doses does not exceed 20 mSv, which is sufficient for the occurrence of cancer and leukemia;
4. Radiosensitivity of an individual depends on its developmental stage and its nutrition level;
5. For different species of animals, plants, fungi and microorganisms the levels of low doses vary widely. These levels depend primarily on the current evolutionary dynamics of radioresistance of particular species and biomarkers chosen for the study of the dose dependence;
6. The results of radiobiological studies on the most sensitive species of organisms with infinitely large samples provide evidences to assert that radiobiological effects may be registered at doses below 10 mGy.

In particular, an example of such a demonstrative case are the results of research carried out at the Institute of Biochemical Physics of Russian Academy of Sciences, led by Professor E.B. Burlakova, described below.

Thus our aim was to analyze the biological effects of low doses, their dependence on the level and duration of exposure, using the data accumulated over the 30 year period after the Chernobyl accident on people, flora and fauna; from the cellular to organismal and population levels. Our objectives were: to discuss and identify mechanisms of observed biological effects, and the characteristics of “low doses” as perceived by different authors. Methods: analysis of data collected in the so-called “natural experimental habitat” of various biological systems (human, birds, insects, plants etc.) in the contaminated area, as well as laboratory studies. Almost all the authors used a "case-control" method of investigation with a statistical significance threshold of 0.05%.

RESULTS AND DISCUSSION

Features of the Biological Action of Low dose Radiation

The objectives of the experiments on biological systems were to assess the structural characteristics of the genome, synaptic and erythrocytes' membranes, lipid composition of membranes, parameters of their oxidation, and functional activity and regulatory properties; in particular, the formation rate of superoxide (HOO^-) radicals, sensitivity of cells, membranes and DNA of organisms to damaging factors induced by γ-radiation (^{137}Cs) of low intensity. It was reported [5] (Figure 1) that radiation dose rate of 6 cGy/day caused extreme changes in structural characteristics of DNA (curve 1) and microviscosity of membrane lipids (curve 2) with accumulation of the dose.

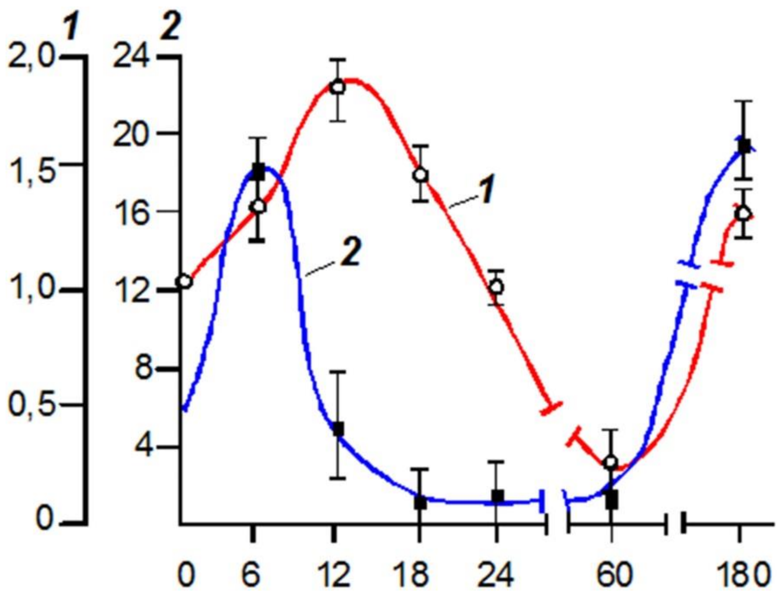

Figure 1. Changing the adsorption of DNA spleen (1) and lipid microviscosity of nuclear membrane (2) depending on the intensity of the radiation dose at 6 cGy/day.

Moreover, the most extreme values were obtained at relatively low doses of 12 and 6 cGy. These values are comparable to changes in the structural characteristics of macromolecules at doses of 20 - 30 times higher (right part of the graph in Figure 1). It was also found that with less intense exposure (0.6 cGy) the maxima of changes shifts to lower doses. DNA absorption maximum is reached at 1.2 cGy. At a dose of 8.4 cGy the absorption does not differ from the control. The functional activity of the cells was found to vary nonlinearly after low dose rate exposure. Furthermore, cells which were exposed with low doses of radiation have a different sensitivity under re-exposure [6].

The effects of low dose IR manifested as a change in structural characteristics of the DNA and membranes, kinetics of enzymes during the entire experimental period after exposure was withheld. The frequency of inversions in mouse spleen was investigated by Hooker where he reported a nonlinear bimodal dose-response (Figure 2).

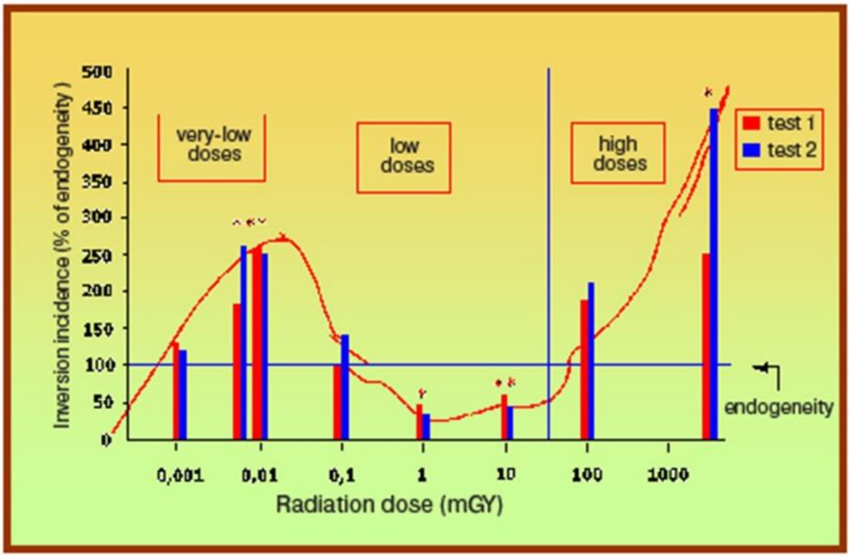

Figure 2. Inversion frequency in the spleen of mice pKZI after the single X – radiation of the whole body (Hooker, 2004).

This way, as a result of numerous experiments the nonlinear bimodal dose-response was established, which can be explained by the gap between exposure, which causes damage in biological systems, and activation of their repair systems (Figure 3).

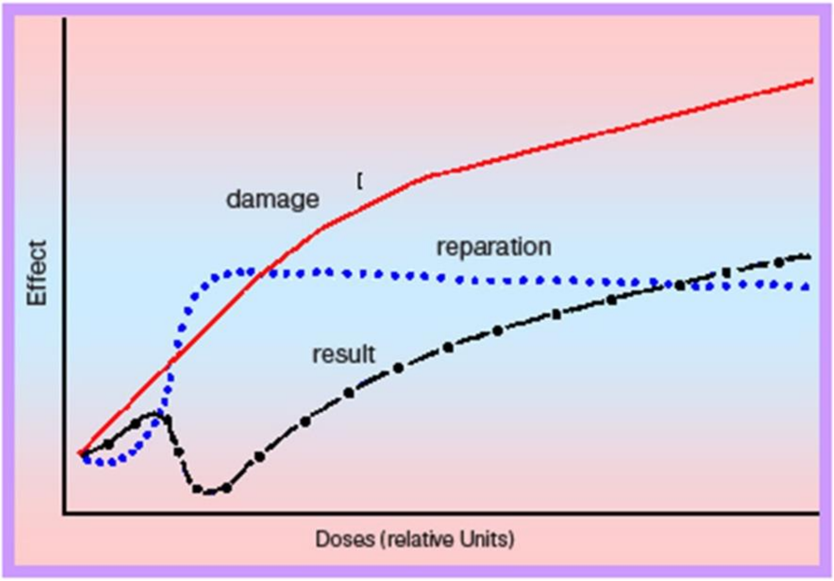

Figure 3. Diagram explaining the non-linear dose response.

Initially, recovery systems delay a little and do not work with full power. Their efficiency increases relatively quickly with increasing dose. Further activation of the recovery processes leads to reaching of the maximum of the repair capabilities. As a result, with the further increase in the total dose of radiation the response may acquire a quasi-linear association, i.e., move to a prior known quasi-linear relationship "dose - effect".

Thus, the reaction of the body to the action of low doses is a complex function of not only dose, but also its power (intensity), the time elapsed since the beginning of exposure as well as the activity of recovery systems.

It should be added that the relative biological effectiveness (RBE) of cytogenetic damage under chronic exposure is higher than in the case of acute IR. This position is supported by numerous experimental data. For example, it was found that chronic exposure at a dose of 2 times lower than in acute exposure has the effect of 3 (% of leaves with trichomes) and 10 times (%area of trichomes coverage on a leaf) than in acute in *Arabidopsis thaliana*. A similar effect as in the acute exposure is achieved by 30 times smaller doses of chronic exposure [7].

The reasons of high RBE values for chronic exposure are due to the fact, that formation of the response in radiated cells, besides the induction of metabolic disturbances that is caused by primary DNA and membrane system damage; is carried by the active reactions involving cell signaling systems. Obviously, in case of chronic exposure, the low dose intensities are perceived by the body as an alarm signal. As a result, signal transduction of radiation forms three responses to chronic exposure: genomic instability, radio adaptation and cell selection. We may find explanation to the manifestations of these three effects in changing of the body's metabolism which is aimed to develop protective reactions against the environmental permanent factor that increases frequency of cytogenetic damage.

There are two strategies for protection against high dose intensities: strategies of ontogenetic and phylogenetic adaptation, as it is shown on the Figure 4.

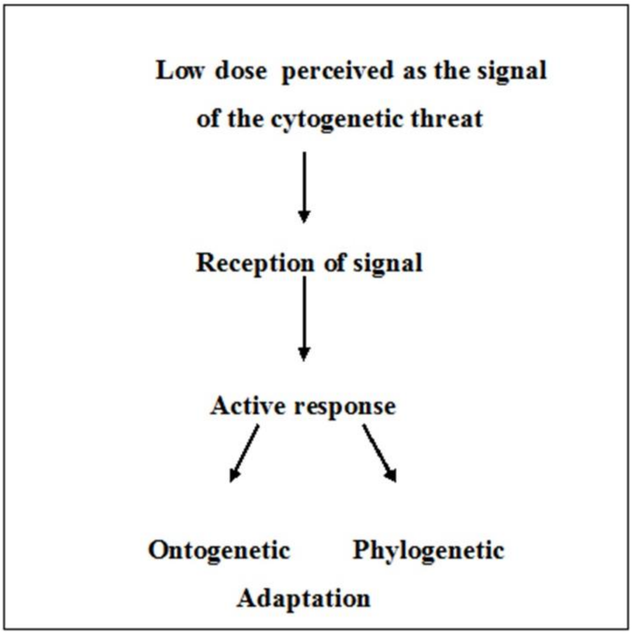

Figure 4. The active cell response to chronic exposure.

Ontogenetic radioadaptation is explained by synthesis of additional DNA repair enzymes, the intensification of endogenous radioprotective activities, achieved by accumulation of sulfhydryl compounds and antimutagens, as well as an increase of the reserve of off-cycle cells. In turn, a phylogenetic adaptation is carried out in an entirely different way –by increasing the rate of spontaneous variation and by natural selection of the individuals, characterized by an increased radioresistance. The radiation-caused induction of genomic instability is one of the mechanisms that increase the spontaneous variation in organisms living in areas with high levels of radioactive contamination. There is a large body of experimental evidence accumulated to date supporting the hypothesis of induction of long term genomic instability. In general, these are data on cytological studies that show increased frequencies of chromosomal aberrations in cells of the body experiencing a chronic exposure. Vivid illustration of genomic instability we see in the collection of mutants of winter wheat, created on the basis of more than 2,000 modified forms of plants sampled in the Chernobyl exclusion zone in 1987 and so far maintained by a low level of radioactive contamination. Levels of variability in this collection are extremely high: in every new generation there is a set of modified forms of wheat with a wide variation of symptoms. Figure 5 shows the next generation of one of the winter wheat lines. It is seen how highly variable the shape of the wheat's spike is. Sometimes there are branching spikes too (Figure 6) [8].

Figure 5. Eared winter wheat plants belonging to the same line.

The increased variability is gained not only by inducing genomic instability, but also through other mechanisms that lead to increased heterozygosity. For example, in the exclusion zone the apomictic mode of reproduction in many species of both animals and plants is replaced by sexual one. This is evident from the data in Table 1.

Table 1. The incidence of Hypericum plant *(Hypericum perforatum*), resulting from the sexual (2n) and apomictic (4n) breeding in the Chernobyl exclusion zone

Comparable levels of radionuclide contamination of surface	Plant Number%	
	2n	4n
Control	62	38
Low pollution (Chernobyl)	81	19
The high level of pollution (Chistogalovka)	85	15

Figure 6.Branching spike of winter wheat. We see a variety of shapes of the ear.

Another new phenomenon is associated with the increased variability rates - the acceleration of the microevolution processes - the emergence of new mutations that may be picked up by natural selection, leading to the appearance of genetically modified forms. Naturally, the results of macroevolution are revealed quickly enough in species with a very quick reproduction rate - bacteria, viruses, micro-fungi. It is shown that in the Exclusion zone the population of *Pucciniagraminis* (cereal rust) gets quickly enriched with highly virulent races, with which the Chernobyl exclusion zone becomes a dissemination center of the disease [9]. An increased variability in the autochthonous populations of viruses and microorganisms is reported as well [10]. Such rapid microevolution is a serious threat to humans and biota in general, and, obviously, requires the development of a methodology for special monitoring of the phenomena caused by this process.

The response of cells and multicellular organisms to chronic exposure described above are due to epigenetic phenomena, the essence of which is that upon the perception of the signal of chronic effects of radiation a special epigenome in cells is selected–a set of expressing genes that control appropriate changes in cell behavior. It should be noted that under radiation the expression in some genes may not be changed, but increases or diminish in the others.

Figure 7 and 8 shows how the expression of two genes changes after plant seedlings be exposed. In one case, exposure was accompanied by a significant increase in expression of the gene, whereas in the other there was a complete shutdown of the gene. These data show very clearly the fact that in response to irradiation the cell launches up active processes that are controlled by the signal systems and epigenetic interactions.

New radiobiological phenomena discovered as a result of post-Chernobyl studies, outline a wide range of problems, the solution of which will lead to the uncovering of new approaches to mitigate the negative effects of chronic exposure on humans and biota.

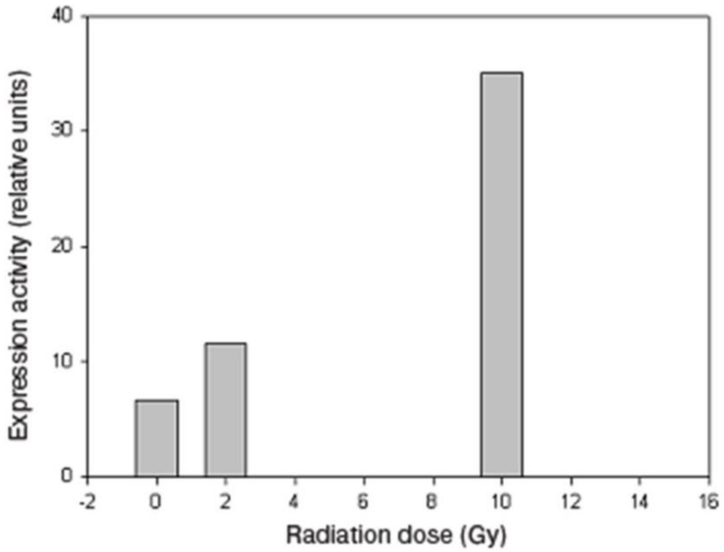

Figure 7. The activity of gene expression controlling the synthesis dehydrin DNH_3, on the fourth day after the radiation exposure of pea seedlings.

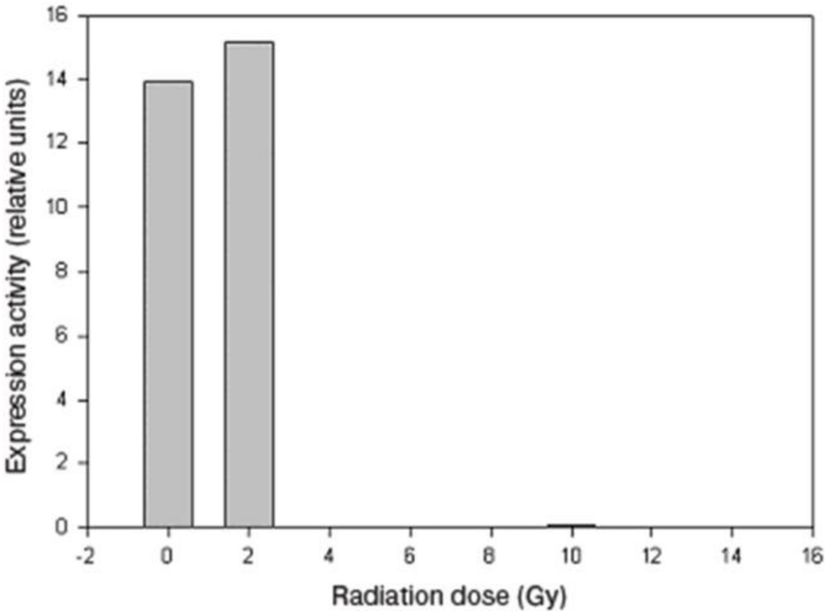

Figure 8. Gene expression activity, controlling division CDC2 cells after 4 days after radiation pea seedlings.

Wildlife Chernobyl: Strong Negative Effects on the Abundance and Biodiversity

Contrary to what is commonly said in many popular newspaper articles, our data suggests that animals Chernobyl are not protected from exposure to radioactive substances. The research team (T. Mousseau– US; A. Moller - France, G. Malinovsky, A. Peklo, S. Rushkovsky, V. Bezrukov - Ukraine) conducted series of field studies on birds, mammals, insects, spiders, reptiles and amphibians. In many cases, the results of research have shown that the number of animals that were born within the exclusion zone and around in the most contaminated areas, was significantly lower than expected to be.

Barn swallow as a biomarker. Swallows (*Hirundorustica*), as well as many other birds, have a feature to come back after wintering to the same place, and often to the same spot where they were born, year after year as they live (usually from one to three years).

A number of individuals in the flock is identified by birds' marking as well as by following the survival of individuals throughout their lives. Birds that do not return to nesting place next year, are considered to have died during that time.

Such biological peculiarity allows a very sensitive assessment of mortality and life expectancy, which in turn enables a direct testing of the impact of pollutants on individuals living in radioactive areas. With this approach, we found that swallows living in radioactively contaminated areas of Ukraine, were more likely to die from exposure to radiation than the birds living in a relatively “clean” areas of Ukraine, Spain and Denmark [11].

The swallows of Chernobyl, which resided in contaminated areas, had a 28% survival rate to the next mating season, while in cleaner regions of Ukraine more than 40% of birds and more than 45% of the birds in uncontaminated sites of Spain usually survived until next year. Important note that this estimate on the survival of swallows is likely to be very conservative as this study included only population with a sufficient amount of live birds, which is a prerequisite for reliable statistical analysis.

In many parts of the Chernobyl zone, especially in areas with higher levels of pollution (above10 mkSv/h), the swallows are so rare that the possibility of their careful study of population demographics is extremely low. Presumably, their populations are small, because the decrease in survival led them almost to extinction. In support of this hypothesis, a radioisotope analyses were carried out on stable (in contrast to radioactive) isotopes of carbon and nitrogen derived from feathers of swallows collected in the Chernobyl zone before and after the accident. Comparisons were made with modern populations living in other regions of Ukraine. The ratios of stable isotopes contained in the feathers, differ significantly depending on the diet and geographical habitat of the birds. When a bird grows feathers (birds renew their feathers every year), these isotope ratios provide a kind of “fingerprint” that can be used to estimate the geographic origin of the individual in the population.

Birds with the same isotopic patterns, perhaps, live in the same neighborhood and eat the same food when they grow feathers, while as individuals with different pattern are likely to live in different places. By using this approach, it was found that modern swallows living in the Chernobyl zone were much more diverse in their isotopic patterns than birds that live in the nearby control areas of Ukraine, where contamination was negligible [12]. In addition, we were able to use the feathers of the stored samples of the museum, which were collected in the Chernobyl region before the accident for comparison, and these birds also demonstrated lower levels of variability. This data supports the hypothesis that the population of swallows in contaminated areas of the Chernobyl zone is supported only by immigrants from outside the zone. In the absence of immigration, the population of the Chernobyl area should have diminished, as the actual native population of Chernobyl must have surely died out, given such low individual survival rates and decreased fertility that was observed in reality.

Swallows from contaminated areas have much more of ten unusal developmental abnormalities that are not usually found in “clean” areas (Figure 9) [13].

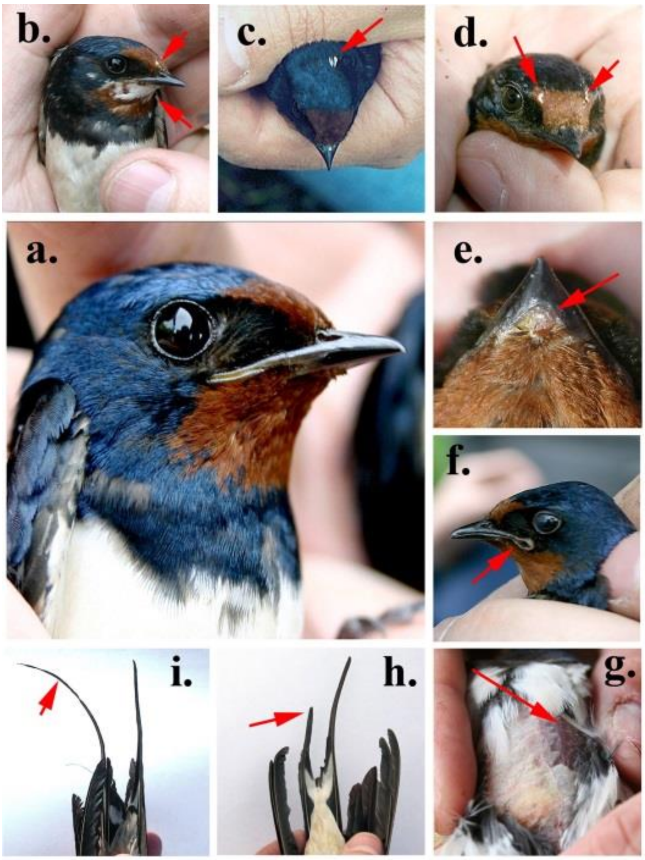

Figure 9. Photos of morphological abnormalities from barn swallows living near Chernobyl: a. normal male. b-d. albinistic feathers on head, throat, and beak. e. tumor on beak. f. deformed lips. g. deformed airbladder. h. extreme tail feather asymmetry. i. bent tail feather and high tail asymmetry (from Moller et al., 2007, copyright T. A. Mousseau, 2007).

In particular, the birds in polluted areas often exhibit signs of partial albinism or deformed normal forms of feathers, in addition to a number of other strains, including tumor on the legs, beak or head and deformed fingers, beaks, eyes and feathers. If one applies the frequency of congenital disorders in the map of Europe showing the level of pollution in the continental scale, it is possible to identify the connection to the high frequency detected in Ukraine and Belarus (about 20%), Medium frequency, observed in the North Italy and Denmark (4 to 5%), and the least (<2%) observed in the Spanish population, where the pollutants associated with the Chernobyl accident, not found. Consequently, there are more than ten-fold excess of deformities in swallows from contaminated areas relatively to the swallows in clean areas.

Investigations of the Bird Communities Revealed Variability in Radiosensitivity

It has been suggested that some of the observed dose-dependent relationships among barns swallows is unique to these species due to reasons associated with their migratory behavior, synanthropic relations and their social habits. To address this hypothesis, in 2006 we launched series of environmental studies of the entire community of birds in the woods in contaminated and control areas of Ukraine and Belarus, which included areas both inside and outside of the Chernobyl exclusion zone.

The research were carried according to profile of the areas, recording the exact location of observation points using GPS and a estimating the level of background radiation. At each location we assessed the abundance and species richness of birds.

For four years (2006-2009.) were covered 726 standardized points of bird nesting sites. We used a standard protocol for ornithologists (for distribution, abundance and species richness) in order to have a reliable way to census of bird populations. The results of these studies were stunning: the contaminated areas had less than 50% of the expected number of species and the total abundance of birds was less than a third of the expected (Figure 10 [14,15]).

It was found that the birds in contaminated areas were either completely absent or were found in small quantities, especially species which have large migration distance, species with more vivid feathering, typically red or yellow color forms, which generally feed on the soil surface insects, as well as the species with large eggs. In addition, the study estimated that the birds of prey in highly radioactive areas appear in smaller quantities, although in “Clean” areas, populations of birds of prey are now growing both inside and outside the exclusion zone [16]. In general, the data on avian biodiversity and abundance clearly show a large negative dose-dependent effect of radioactivity on the bird population of the region of Chernobyl (Figure 10).

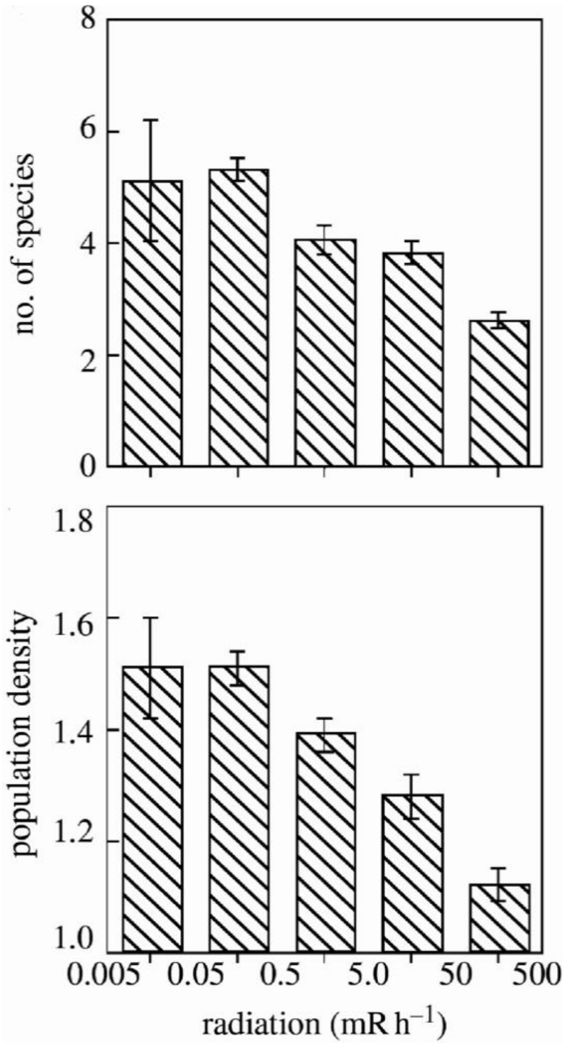

Figure 10. Biodiversity (species numbers) and relative abundance of forest birds (all species) versus background radiation levels in the Chernobyl Zone (from Moller and Mousseau 2007).

Mammals, bees, butterflies and spiders. It is possible that the birds as a group are particularly vulnerable class of organisms with a very high metabolic rate and the unique life history. However, series of environmental studies, called to census common groups of insects, spiders, amphibians, reptiles, in the same manner as for the birds, were carried during the spring and summer 2006. These studies showed a significant reduction in the abundance with increasing levels of background radiation in the Chernobyl zone. Also, observations were performed for the populations of mammals in the winter, by identifying and counting the footprints on fresh snow on the ground [17].

The conclusion these studies related to prevalence mammals is perhaps the most provocative. Many posts in newspapers suggest that mammals, especially large ones, such as elks, deer, wolves and wild boars allegedly thrive in Chernobyl zone. However, such information contradicts to the researchers' conclusions, which are based on monthly observations of the exclusion zone for more than 10 years – there is a relative lack of large animals, despite the absence of human influence after the accident (e.g., hunting). This is of particular concern because, for instance, such decrease in populations is unusual for reservations and protected areas in other parts of the world that are facing the consequences of uncontrolled growth populations: the majority of organisms are able to quickly overpopulate their habitat if predators (primarily humans) are exiled from the system. Nevertheless this does not apply to Chernobyl, where the discovery of large mammals is actually quite a rare event.

In order to evaluate the abundance of mammals, we conducted series of observations of the mammal species, which are relatively easy to identify by tracks on fresh snow. By using standard ecological methods, we demonstrated that the number of mammals was significantly lower in highly contaminated areas of the Chernobyl zone, and that the changes in the level of background radiation explain about 20% of the difference in population size of mammals [17].

If the prevalence of mammals in clean areas within the Exclusion zone is significantly higher than outside the zone, our data clearly indicates that the species prevalence in the area is significantly reduced in a dose dependent manner with increasing levels of background radiation.

Thus, with few exceptions, wildlife within the Chernobyl zone shows some good examples of reducing of the prevalence and diversity of species in accordance with the levels of background radiation. Abnormal pattern is also observed in the contaminated areas of Belarus, where the human population has returned home and is engaged in agriculture. Broader implications arising from these data include the assessment of the risks and hazards associated with the return of the population to the contaminated areas and the use of land for agriculture, forestry and tourism.

On the Health Effects of Radiation Exposure

Leukemia. We were able to evaluate the general relationship (Figure 11) of the dose-effect (number of deaths from leukemia for every 10^5 person-years) at low doses exposure, using the data before and after the Chernobyl studies of workers in the nuclear industry in the USA, Canada, UK, studies of human populations in Japan subjected to atomic bombing of Hiroshima and Nagasaki, research of the South Urals area that has been affected by the accident at Techa River in 1957 [5]. Depending on the chart build the results may be interpreted differently. The plot in Figure 11a is in a normal scale. Therefore, the data at the beginning of the chart (0-250 mSv) form a cloud, which cannot be interpreted. On Figure 11b the same data is plotted in a semi-logarithmic scale. As a result, instead of a random cloud of dots we see their logical distribution. It clearly shows that collected data on lethal leukemia cases has a bimodal relationship. Moreover, the first part of the curve is described by a hyperbolic model with the sharp rise and subsequent steep decline with increasing of the dose. The second part of the curve (starting from 100 mSv) corresponds to the hyperbolic dependence with high levels of correlation and determination. In this portion of the curve (100 to 1000 mSv) with some degree of schematization can be interpreted as a quasi-linear. The general character of the curve indicates that approximately in the interval of 17 - 19 to 1000 mSv the body compensation possibility are activated.

They lead to a decline in the curve after the initial rise and subsequent quasilinear gradual rise with an increase in dose to about 1000 mSv. Further increase of the dose leads to failure of the compensatory capacity of the organism and a rapid increase of the death rates. This result leads to the following conclusions:

- Mortality rates from leukemia during exposure in low doses can be comparable with the mortality rates for tens of times higher doses.
- According to the curve, for the low dose (10 mSv) radiation along with the part of high effect , there is allocated another subsequent part in which with increase of the dose there is a significant decrease in

effect until the change in its sign, i.e., to reduce deaths from leukemia to lower than in control.

- Variation of the dose-effect relationship at this stage of research allows to infer at least two possible mechanisms explaining mortality from leukemia at low and high doses.

The first of them implies this might be the effect of low doses of radiation as a leukemia-promoting factor and of high doses - as inducer of leukemia. The second possible mechanism is due to the above-mentioned different ratio between radiation-induced damage and activity of recovery systems at low and high doses.

In any case, most of the effects are not directly induced by radiation, but they are caused indirectly through metabolic processes, particularly change in the immune and antioxidant status of the body as well as through variation in sensitivity to environmental factors.

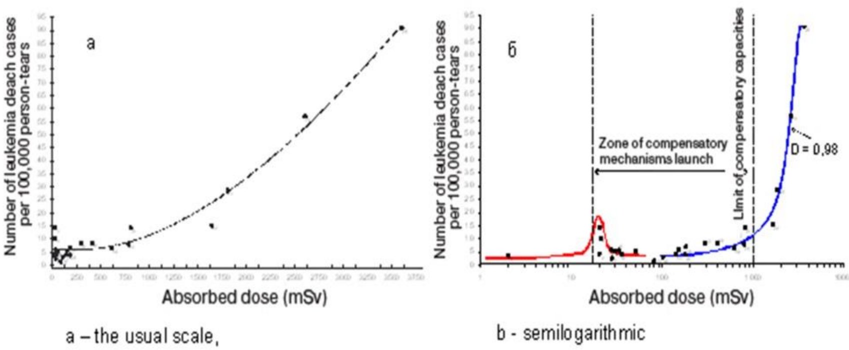

Figure 11. Data on the number of deaths from leukemia at 100 thousand person-years (depending on the absorbed dose, mSv).

On the Health Condition of Liquidators of the Chernobyl Accident

Verification of these findings by supervision of health status of the clean-up workers (liquidators) of the Chernobyl accident according to clinical studies revealed the following. Alteration in some metabolic processes, e.g., regulation of lipid peroxidation was observed even in apparently healthy liquidators. At the same time, one should keep in mind that the system of membrane lipid peroxidation is strongly associated with other systems of cellular regulation, which are responsible for the resistance of cells to damaging factors as well as the immune system, the aging process, development of cardiovascular, neuropsychiatric disorders, etc.

There also has been observed a decrease of vitamin E in the blood of the liquidators (as in Chernobyl swallows [13]) and blood antioxidant – ceruloplasmin, whilst the concentration of free radicals was increased. In other words, the antioxidant status was altered in a negative direction.

It is known that in a certain range of radiation doses their qualitative differences can be assessed by looking into rates of chromosomal aberrations, as well as by studying dicentric and centric rings in lymphocytes. Thus it allows the use of cytogenetic analysis for biodosimetry research. In one such study 5 groups of liquidators with chromosomal aberrations varying from 0.5% to more than 2% were surveyed. It was determined that the mean radiation dose received by them was 15 cGy. The obtained parameters for these groups were compared with the control group. The results of analysis demonstrated that the cohort of liquidators with the minimum number of chromosomal aberrations (<0.5%) differed from the control more than any other experimental groups. This means that changes in the parameters of antioxidant status they had, were the most significant, pointing to the risk of serious disturbances in the regulation of lipid peroxidation. In other words, we can assume that we are dealing with nosological pathology, which from time to time may be compensated and does not manifest clinically, but under certain conditions can be appeared in a variety of diseases. The variation of effects at different doses has also shown that it is impossible to calculate the risk of disease for the entire cohort radiated as a whole, regardless of dose.

Thus, not only the experimental data on animals, but also the results of clinical trials in general liquidators stacked nonlinear dose-effect relationship.

New Radiocerebral Effects

Chernobyl changed radically the conservative views on radiobiology. One of the most striking changes is radiocerebral effect. It was orthodoxally thought that the nervous system is classically radioresistant. However, the Chernobyl disaster has provided a dramatic empirical evidence, which denied this seemingly unshakable position.

Developing brain proved to be extremely radiosensitive. The Project №3 «Health Effects of the Chernobyl accident” Franco-German Chernobyl

Initiative studied the potential effects of prenatal exposure on the brain prenatally exposed children and showed no cases of severe mental retardation and microcephaly, but there were diagnosed significantly more psychological development disorders, emotional, behavioral and organic mental disorders, as well as paroxysmal conditions. Their general IQ score was lower due to lower values of verbal IQ, and, as the result, the frequency of disharmonious intelligence was higher (Figure 12). Also the development of the dominant hemisphere was altered (according to the results of neuropsychological and neurophysiological studies) [18]. As seen from Figure12, these effects by embryo and fetus are manifested at low doses above 20 mSv. These data were confirmed by results of the research conducted by Norwegian and American colleagues [19].

In radiation accident at a nuclear reactor, which is accompanied by a massive release of radioactive iodine in the environment, most critically the cerebrogenesis may be affected at later stages of gestation (16-25 weeks) (Figure 13).

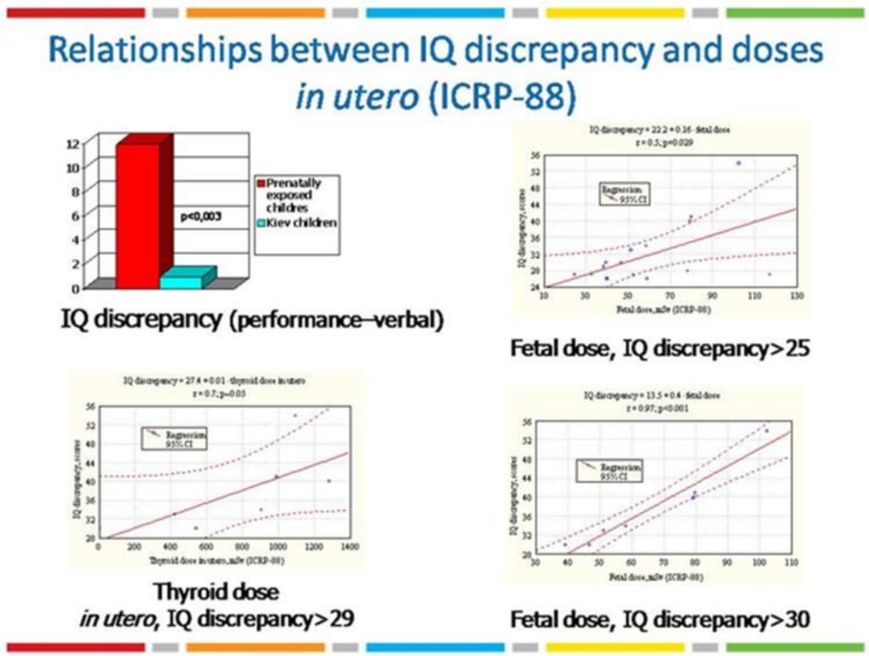

Figure12. Relationships between IQ discrepancy and radiation doses *in utero* (ICRP-88) (adapted from Nyagu et al. [20] by Loganovsky et al., 2008).

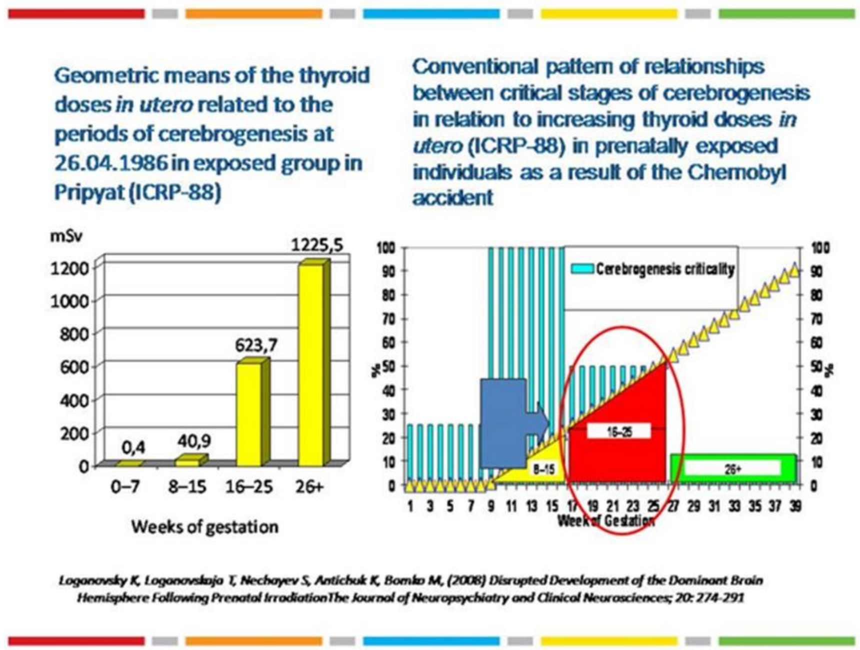

Figure 13. Conventional pattern of relationships between critical stages of cerebrogenesis in relation to increasing thyroid doses *in utero* (ICRP-88) in prenatally exposed individuals as a result of the Chernobyl accident (adapted from Loganovsky et al., 2008).

Thus, the results of recent studies indicate that subclinical radiation damage human embryo and fetus may occur in cognitive deficits and other neuropsychiatric disorders. And these previously unrecognized, long-term neuropsychiatric effects may be due to relatively short-term exposure to radioactive fallout, the levels of which were considered as safe [21].

In the adult population affected by radiation accident, as well as the liquidators there were also found some neuropsychiatric effects. For example, the staff of the Chernobyl exclusion zone, compared with the general population in 1990 There was a significant increase in the incidence of schizophrenia (5,4 cases to 10000 people in zone and 1,1cases to 10000 people in Ukraine, 1990 (Figure14) [22]. In the evacuated people from the Chernobyl exclusion zone, who had 0.3Gythyroid dose, were increased the risk of cerebrovascular disease, and at doses of 2 Gy - were increased the risk of mental disorders [23]. The results of the current mental health assessment in randomized samples representative cohort of liquidators and evacuees from the Chernobyl exclusion zone, which are registered in the IEP SE "SCRM NAMS of Ukraine" [24], confirm the presence of long-term mental health consequences of the Chernobyl disaster. At the liquidators and evacuated much more mental and behavioral disorders in general. In addition, the liquidators increased incidence of disorders such as organic depressive alarmingly organic, organic emotionally labile (asthenic) and organic personality disorder.

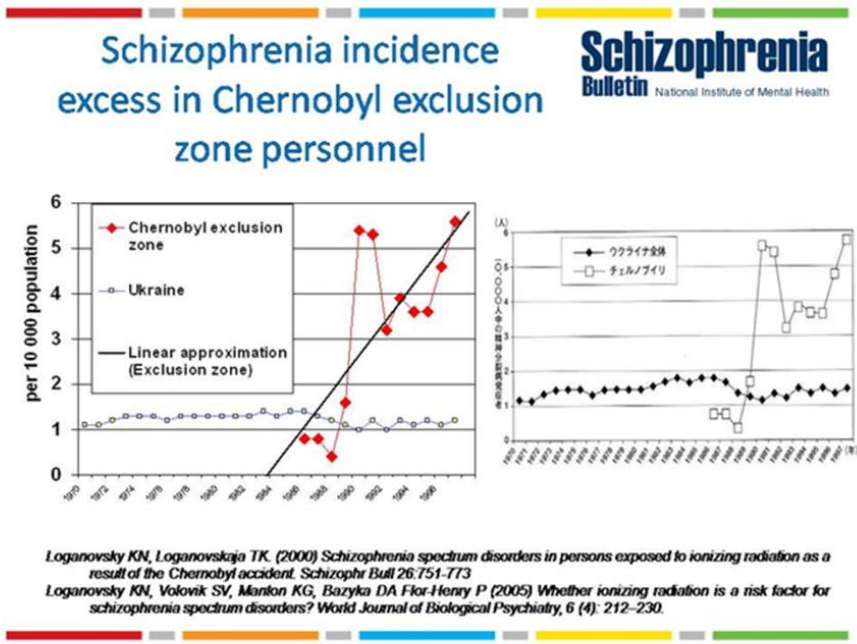

Figure 14. Schizophrenia incidence excess in Chernobyl exclusion zone personnel.

Chronic fatigue syndrome (CFS) is suggested as the most apparent consequence of radio-ecological disaster [25- 27]. A significant proportion of the liquidators, as well as the staff of the CEZ, and those working near the Shelter Object, that were exposed to low doses (<0.3 Gy) of IR are manifesting pathologies, which correspond to this syndrome. We hypothesized about the development of CFS due to the effects of low and very low doses of radiation in combination with psychological stress [25 - 27].Symptoms of post-radiation syndrome and its chronic flow are comparable or sometimes identical to CFS and could be possibly explained by the biochemical cycle "nitric oxide/peroxynitrite" [NO/ONOO (-)] [28]. CFS predisposes to neurodegeneration, cognitive deficits and other neuropsychiatric disorders generally induced by environmental effects [29,30]. Abnormalites in the mitochondrial genome, in relation to changes in transmembrane ion transport, may underlie the formation of CFS and metabolic syndrome X (MSX). Radiation-induced damage to mitochondrial DNA in tissues with low proliferative activity may be one of the mechanisms of pathogenesis, increased non-cancerous morbidity and mortality associated with low doses of IR [31]. There is no doubt we need a verification of the obtained results within international collaborative research with the establishment of the neurobiological bases of neuropsychiatric effects of the individuals exposed to low doses of ionizing radiation.

After 18 years of the accident liquidators showed significantly higher levels of depression (18.0% vs 13.1% of the Ukrainian population) and suicidal ideation (9.2% vs 4.1%, respectively), whereas the incidence of alcoholism and intermittent explosive disorder (IED)was not increased. Throughout the year before the survey there was documented an increased frequency of depression (14.9% vs 7.1%), post-traumatic stress disorder (PTSD) (4,1% vs 1,0%) and headaches (69.2% vs 12.4%). Exposure level was associated with the severity of somatic symptoms and existing PTSD. Thus, the liquidators demonstrated long-term effects of the Chernobyl disaster on the status of their mental health.

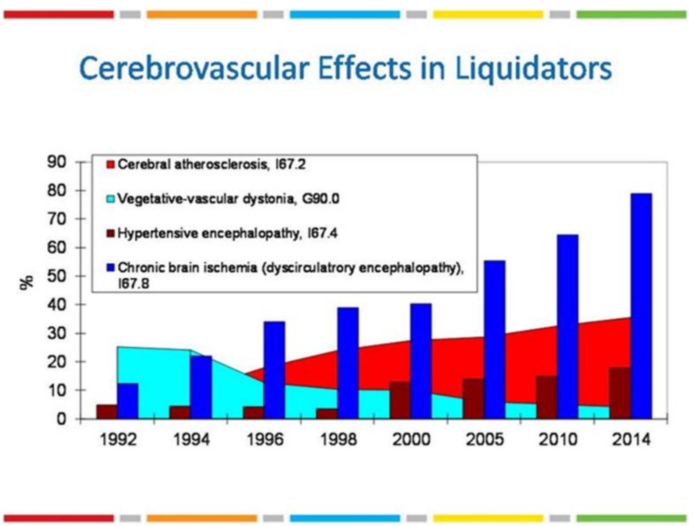

Figure 15. Cerebrovascular Effects in Liquidators.

Epidemiological evidence was obtained suggesting an increase in frequency of mental disorders, as well as the cerebrovascular disease in liquidators in presence of radiation risks at doses greater than 0.25-0.5 Gy [23; 32,33]. Statistically significant radiation risk of cerebrovascular pathology in liquidators was detected at doses greater than 0.15 Gy [34].

The frequency of vegetative-vascular dystonia during the years after the accident has decreased significantly and currently accounts for about 5% of a representative sample of liquidators. At the same time there was a significant increase in the incidence of cerebrovascular pathologies - primarily chronic cerebral ischemia (ICD-10:167.8), cerebral atherosclerosis (167.2) and (167.4) hypertensive encephalopathy (Figure 15).

The researchers have found an association between effects of the Chernobyl disaster and the development of alcohol-dependence syndrome that manifests over the already arisen mental disorders in liquidators [35]. Radiation damage and age of an individual affect synergistically that results in accelerated aging. It should be emphasized that different authors did found independently a consistent evidence of organic brain damage and accelerated aging of the central nervous system in the Chernobyl liquidators. The overall incidence of neuropsychiatric disorders is higher in affected elderly people. However, the dynamic of this morbidity in younger people is more aggressive. Thus, the potential for radiation induced neuropsychiatric effects should be attributed primarily to accelerated aging and neurodegeneration [36-44]. Accelerated aging of the liquidators was confirmed by the results of a comprehensive survey. Modern instrumental methods of research allowed to prove that all of these neuropsychiatric disorders have an organic basis - brain damage [45-47].

Such clinical effects, with established radiation risks, as increased risk of cerebrovascular diseases, increased mortality from circulatory diseases in adults, cognitive deficits in children, mental retardation in children after prenatal exposure, can be attributed to the effects of low doses of less than 50 cGy. Thus these estimates may be considered as an upper threshold of low doses [48].

Dopplerechography of the cerebral hemodynamics as well as visualizing of the neural morphometry and electrography have demonstrated effects of the radiation-based brain damage in clean-up workers that received a dose more than 0.3 Gy. The symptoms, including ARS showed correlation of brain activity on the state of its structures, which suggests that each violation of cerebral function correspond to structural changes. It is noted that both white and gray matter of the brain are responding to IR, which is brings about cortical atrophy of the cerebral hemispheres, disrupting of the corticolimbic system, involution of blood vessels, etc. It is due to the presence of schizotypal patterns in front-temporal dysfunction in left hemisphere of exposed individuals that suggested the diathesis-based hypothesis of IR as a risk factor for schizophrenia spectrum disorders [24; 49-51]. There are found some evidences in clinic studies that support these assumptions as well as in experimental radio-neuro-embryological studies. The cytotoxic and humoral mechanisms (neuropeptides, cerebral antibodies, neurotrophiclymphokines, hormones, etc.) provide a new perspective on the pathogenesis of neuropsychiatric radiation effects [51].

25 years of research after the greatest man-made disaster in the mankind history have clearly shown that the central nervous system plays a key role in adaptation to changing environmental conditions.

Chernobyl has drastically forced to reconsider the conservative views in radiation medicine, in particular:

- on the radiosensitivity of the central nervous system;
- on the new radiocerebral effects and their occurence at doses below 0.3 Gy.

Overall accumulated data allowed V. A. Buzunov and K. N. Loganovsky (author of this section) to suggest cerebrovascular, and some neural and mental diseases in Chernobyl liquidators as stochastic effects of radiation exposure in low doses. The same also applies to other non-cancer diseases, particularly cardiovascular diseases with defined radiation risks. In other words, we are implying about the effects that occur at random and can occur even without a threshold dose, whilst the dose is proportional only to probability of their manifestation, although the severity of these effects is not dependent on the dose. We believe this is perhaps the main and fundamentally new lesson of Chernobyl.

Radiation and Landscape Factors of Child Morbidity

Child population of the contaminated areas is particularly sensitive to radiation exposure. Their gastro-intestinal tract becomes one of the first radiation-affected systems due to the fact that within the contaminated territories there are consumed mostly local and thus also contaminated products. Analysis of the pathologies of the digestive system in children affected by the Chernobyl accident was carried out by a number of researchers, in particular, by N. A. Korol, L. K. Bayda, A. V. Degtyareva, and M. V. Naboka et al. [52-56]. The increased incidence was mainly characterized by chronic diseases like gastritis, gastroduodenitis, gastric and duodenal ulcers, liver disease, gall bladder and pancreas disfunction, dental caries, and others. The possible reasons for the growth of the disease incidence were considered the radiation factor, psychological stress caused by the accident and the economic consequences of the following collapse of the USSR.

Lack of a complete and reliable dose control in the analysis of the diseases has been long time used for the actual denial or belittling the role of radiation in these (and many other as well) forms of somatic pathologies. At the same time, this doubtful approach was typical for the various international reports and conclusions (WHO, 1989; IAEA, 1991, the project IRNESA, UNSCEAR, 2000; Proceedings of the Chernobyl Forum, 2005 et al.). This was motivated by the need for strict correctness of the research, which is naturally appraised. Unfortunately there were rare attempts for an evidence-based scientific prognosis of the processes and the diseases associated with those. In fact, such prediction has to be based on a comparative evaluation of the role of individual factors based on the Japanese, Soviet (Kyshtym) and the Chernobyl experience.

Because of the indeed poor assessment of the acquired dose, we thus pay attention to the actual contamination (mainly by ^{137}Cs) of the territories where people live. In this case, the samples for analysis were typically chosen on the administrative basis of and did not include other principles.

The investigation of the patterns of radionuclide migration in the system “soil –plants – food products” demonstrated that the intensity of this migration, crucially depends on the geochemical characteristics of the soil and on the landscape in particular. The coefficients of radionuclide transfer (primarily the main dose-forming - ^{137}Cs) reach maximum for acidic soils and for associated geochemical landscapes. The minimum values of the transition coefficients are characteristic of calcium-rich ‘chernozem’ (black, humus-rich soil) landscapes [57-58].

This soil-landscape framework allows to more correctly consider possible effects of radiation on the human body in terms of spatial analysis of a disease and, in particular, is useful for interpolation and extrapolation procedures. As a result of using this framework, the conditions are provided for not only better evaluation of radiation exposure, but also for possible, at least in part, identification of other negative influences. For comparison there were used the data on prevalence and primary incidence of a disease, which were collected by a unified protocol over the whole territory of Ukraine (the proportion of a provided medical aid for 1000 of child population per year). Measures for chronic (re-) incidence were calculated as the difference between the prevalence and primary incidence of a disease.

Application of this principle in example of Zhytomyr (Ukraine) region brought about the idea of dividing of the area into at least two substantially different regions - the North region with predominantly acidic geochemical landscapes and South region with mainly calcium-rich landscapes. It should also be kept in mind that the North region is characterized by iodine deficiency. All subsequent analyses were performed separately according to this division. In order to assess the relative risks there was used a control data obtained from low-contaminated districts of the North region. Additionally, the non-radiation factors were assessed using the of data low-contaminated areas of the South Region. Studies were carried out by an international team (Ukraine - M. Naboka, A. Lihosherstov, E. Chaban, V. Shestopalov; United States - E. Svendsen, W. Karmaus).

The research included 22 years of observations (time series incidence from 1988 to 2009) andv53845 children. North Region given acidic landscape includes areas with average cesium-137 concentration varying from 8 to 383 kBq/m^2. Average pollution in the South region reaches 2 - 6 kBq/m^2.

Figure 16 and 17 shows the averaged curves of the prevalence of noninfectional gastrointestinal disease in children of the North (17) and South (18) districts of Zhytomyr region. The most notable patterns are following:

1. The prevalence of diseases in children in the North was in the range of 50 - 450, and in the south was in the range of 50 – 150 (cases per 1000 children per year). It should be emphasized that the difference in values of the North and South regions was statistically significant.
2. Prevalence of disease in the North territories is characterized by significant growth during years 1997 - 2002, which was common for most contaminated areas, and then there was some step down to the level of 130 - 300, which we attribute to a decrease in the observed cumulative dose in children, if we exclude the data on those born in1986 - 1987. In the south, there was no general pattern: the values fluctuated around the intercept.
3. The prevalence of disease was increased by 2.5 - 4.6 times in the North districts compared with the initial observation period. If

compared to such levels of the control area the relative risk was increased by 2.5 - 6.5 times.

4. The relative risk of chronic (recurring) disease in the North regions had a tendency to increase throughout the observation period, increasing from 1 - 2 to 5 - 18, i.e., 2.5 - 15 times. In the South region of the growth in the relative risk of chronic diseases began 12 years later in the period 1998 - 2002 increased during this time from 1.6 - 2.5 to 2.6 - 6.5, i.e., 1 - 4 times.
5. At the beginning of the observation period (1988 - 1992) prevalence estimates of the primary and chronic disease in the North and the South districts were close to each other and did not differ significantly.
6. Separate analysis of the indicators of pre-school and school-age morbidity revealed differences in incidences of GID diseases, especially primary incidence. The incidence of pre-school children in the North and the South is almost the same (44,8 and 48,2‰ respectively), and is almost doubled for school-aged kids (108.7, respectively, and 66‰). Failure to detect difference in terms of morbidity in preschool children might be explained by some age-related particularities of the body. For children of pre-school age the infectious diseases gastrointestinal tract are most common. However, with increasing of the length of residence in the contaminated areas the non-infectious diseases gastrointestinal in children become growing. Previous epidemiological studies (1990-2001 [59]) showed that the relative risk in 3.5 (3,4-4,57 CI) times higher in the most contaminated area (^{137}Cs 383 kBq/m^2)than the control (^{137}Cs 15 kBq/m^2).
7. Simulation of association of infectious increases and contamination levelby^{137} Cs of the North region has showed a nonlinear dependence on the duration and level of exposure. According to the results, only after a certain time of chronic exposure to ^{137} Cs its effect on the growth of infant morbidity becomes significant ($p < 0,00001$). As it is well known [60], the specific effects of chronic exposure are found in a cumulative effect of low dose radiation after a long exposure time. Such situation is typical not only for the residents of contaminated areas, but also staff of the nuclear industry, etc.
8. Evaluation of gastrointestinal diseases of children by a dose-dependent manner, carried over the Ovruch district of the North region [61] suggests that their association with chronic radiation in low doses is nonlinear and that it takes a few years to accumulate

additional dose to 7 mSv of ^{137}Cs. After this is met, a steady increase in the incidence can be found.

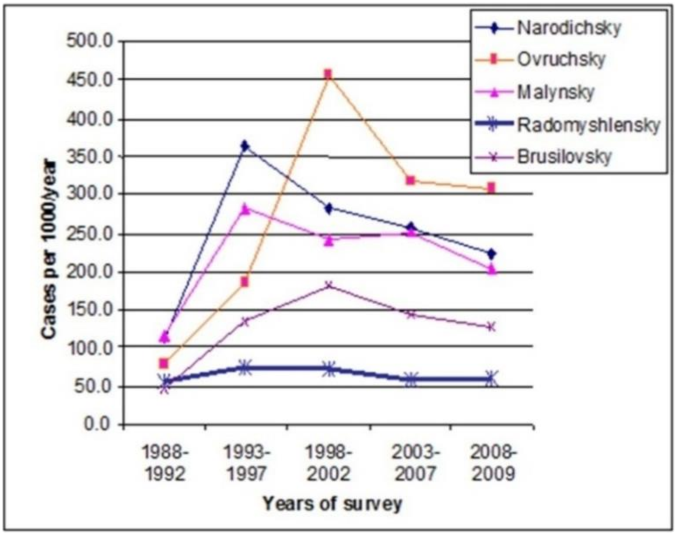

Figure 16. Dynamics of prevalence of gastrointestinal (GIT) disease in children 0-14 years from radioactively contaminated northern districts of Zhytomyr region (1988-2009).

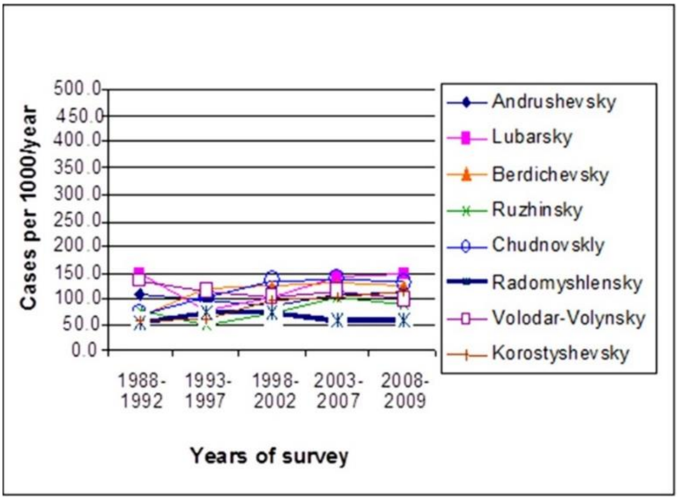

Figure 17. Dynamics of prevalence of GIT diseases in children 0-14 years from little polluted southern districts of Zhytomyr region (1988-2009).

Thus, the results indicate the following.

- We report another evidence which supports findings of previous authors - the incidence of disease increases with chronic exposure to low doses, and that the dose-effect association is nonlinear. As it can be seen from the data we provide, a stable increase of the GID disease incidence in children of the North Region (resulted from a slight chronic dose load) is found a few years after the accident and is enhanced after 1997, when there was some additional accumulation of the dose, which according to estimates Ovruch district was about 7 mSv.
- The dynamics of disease incidence and, respectively, growth of the relative risk in very weakly polluted areas of South region begins only in 1998 - 2002 years, and those values were significantly lower than in the Nordic region.
- Apparently, if the psychological stress caused by the Chernobyl accident and further one caused by the collapse of the Soviet Unions have had any essential effect in terms of the poorer rural areas, we would not have seen such significant differences in incidence between the North and South regions.
- Screening effect was insignificant as in the North region the primary incidence of disease grew gradually and proportionally along with indicators of chronic diseases, whereas in the South region in 5 out of 8 districts there was a decrease in morbidity and in 3 remaining ones a weak growth was documented. If the effect of screening had existed, these differences would not have been so apparent.
- In the North region the children conceived and born in 1986 received a relatively more intense exposure, including impact from iodine from the west trail, subsequent chronic exposure due to contamination of soil with ^{137}Cs by values higher than 30 - 50 kBq/m^2 aggravated by high rates of radionuclide transition. Children of the South region have not experienced such relatively short impact and chronic exposure was significantly lower. It can, however, be suggested that chronically accumulated dose over time and prevalence of local products could contribute to some increase in the disease incidence, which was supported by research performed by E.N. Stepanova et al. [62] on the medical examinations of children of Narodichi area, although overall that requires more confirmations by further research.

- From this study it may be inferred that child population, which living in the geochemical conditions of iodine deficiency and increased migration of radionuclides in the system “soil –plants – food products” is characterized by a significantly higher disease risk in terms of chronic exposure after the accumulation of a certain relatively low dose. This requires a further careful analysis and a comprehensive deduction of relatively low dose limits for children living in such conditions. Until now, especially for children, the dose limits are not normalized, though children are noted for their high radiation sensitivity.

CONCLUSION

1. The described examples of new knowledge, which were received in analyses of the complex pre- and post-Chernobyl date, do not embrace all of the possible aspects of the problem. But even they allow to recognize that:

    - low doses of radiation actively influence the biota and human;
    - in some intervals of the low doses, the low-intense chronic exposure is more effective (thus more dangerous) than acute one;
    - the value of the low dose, at which its effect reaches the local maxima (extremes), may vary depending on intensity of IR, i.e., can be shifted downward with decreasing in IR intensity;
    - the organism’s response to low doses is a complex function not only of the IR dose, but also the IR intensity, the time elapsed since the beginning of radiation, and the time that it takes to activate the cellular recovery (repair) systems;
    - in most cases radiation in low doses also increases sensitivity to exposure damaging factors;
    - many of the effects are not directly induced by radiation, but indirectly through humoral regulation, through a change in the immune and antioxidant status of the body, as well as through sensitivity to environmental factors;
    - both experimental data on wild animals and clinical studies on clean-up workers reveal a general nonlinear dose-effect relationship;

- chronic exposure to IR leads to increased long-term genomic instability, and as a result, to increased variation in exposed population, which brings the formation of mutants. In fact, some microorganisms become highly virulent and which may be threatening human and biota;
- autochthonous (local) fauna of the Chernobyl Exclusion Zone (birds, mammals, insects)demonstrates diminishing of native population(low individual survival rates, excess of deformities and decreased fertility) and decline in the diversity of species, in accordance with the levels of background radiation and despite the lifting of the press of human presence, the population in contaminated areas of the Chernobyl zone is supported only by immigrants from outside the zone.
- the incidence (but not a severity) of gastrointestinal diseases in children is clearly associated with the geochemical patterns of the landscape with increased radiation conditions. It also corresponds to the radionuclides' transition rates in the system "soil –plant–food product" however shows no association with the emotional, social and screening effects in studies of detail achieved.

2. Numerous studies of the Chernobyl aftermath report dose-related radiocerebral effects in children and adults. These findings have led to a fundamental change in our understanding of the sensitivity of the human nervous system to radiation exposure, leading to the conclusion about general stochasticity of effects of low doses of radiation on the nervous system and mental condition and gastrointestinal diseases of the people. The same we can say about the gastroduodenum system of the children. That is, we are talking about non-cancer effects, which occur randomly and can occur even without a threshold dose. That's being said, we emphasize, that increase of the dose is strongly proportional to probability of the effect , however severity of these effects is not depend with the dose.
3. All the above demonstrates the need for a more serious approach to the problem of minimizing and avoiding exposure to any low doses. The effects of low doses are comparable in their health consequences to the effects of relatively higher doses. Thus, developing of the systems of prevention and protection from IR should be one of the most important issues of the respective governmental structures, international organizations and the international communities of all levels. These regulations must account some dangerous nuclear

facilities and plants, and, at the global level, prevent any further radiological accidents such as Chernobyl (Ukraine), or Fukushima (Japan), let alone test nuclear weapons that greatly contributed to global background radiation.

4. The accumulated negative experience of nuclear accidents raises more questions on the need of tighten the international recommendations and the requirements for countries and companies that are operating the existing or are intending to operate new nuclear power plants. These regulations must evaluate and compare the achieved progress and the required safety culture in the states or companies. The latter should be evaluated by conclusions of international auditing. It is necessary to develop regulations, the practical application of which will improve the activity of the IAEA and nuclear liability of the UN and, eventually, global radiation safety and will contribute to the minimization of existing and future risk .
5. We must admit the gradual rise of the regional and global background radiation, which poses the obvious environmental hazard and should be suspended.
6. Potential radiation hazards and risks of accidents should be scrutinized at various levels (including design) of nuclear power plants with account for geochemical and radioecological statuses. The latter must be covered by respective certification and be zoned in terms of their suitability for further use in the event of an accident, in the developing of protocols of necessary rehabilitating activities. These also should account for the following economic costs and recommended preliminary efforts towards preparation for such events. All this must be accomplished before any hypothetical possibility of the accident, ranging from project and design, construction and to operation of any nuclear power plants.
7. A broad health program should be developed and strictly implemented for increased care of the population living in the contaminated area in order to prevent negative effects of low doses of radiation and other associated environmental factors.
8. Already obtained knowledge about the various effects of radiation in relation to man and biota accentuate the extreme importance of deepening of research, bringing ideas and designs for the protection of life on Earth as a whole, and for conservation of the health of present and future generations of people, in particular. Therefore, it is still

quite relevant to support international and national research programs in no lesser priority than 5 - 10 or 20 years ago.

Ukrainian authors of this first publication call attention that there can be no argumentation for practice of cutting down the Chernobyl studies in such states like Ukraine, where they have been practiced over the last decade, since Ukraine is in the epicenter of the accident and has the most interest in the results of such studies.

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BIOGRAPHICAL SKETCH

Marina Naboka, PhD
NAS of Ukraine
Address: Radioecologycal Center of NAS of Ukraine, 55-b Gonchar St., Kiev, Ukraine , 01053

Research and Professional Experience:
Environmental Health, Radioecology, Medical Geology

Professional Appointments: Senior Scientist

Honors: Fulbrighter

Publications Last Three Years:

Publication last year:

Jelin, BA, Sun, W., Kravets, A, Naboka, M, Stepanova, EI, Vdovenko, VY, Karmaus, WJ, Lichosherstov, A, Svendsen, ER. (2015). Quantifying annual internal effective ^{137}Cesium dose utilizing direct body-burden measurement and ecological dose modeling. *Journal of Exposure Science and Environmental Epidemiology* 2015, March doi:10.1038/jes..6http:// www.nature.com/jes/journal/vaop/ncurrent/full/jes20156a.html.

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Marina Naboka, PhD, Kiev Medical University graduate, Scientist in Radioecologycal Center of National Academy of Scienceof Ukraine, where she works from 1993 y. as Head of eco-hygienic department and Senior Scientist till now, Fulbrighter, Visitor Professor in University of South Carolina,Licvidator (clean-up worker) of Chernobyl accident she is author and co-author above 100 publication. She has major scientific interestin health of children population of radiocontaminated territory, natural conditions, first of all landscape geochemical,which can promote radiocesium and etc. toxicants duringfood link soil-plant to human and different habitants such territory, common bioeffects of chronic exposure of low dose for human and biota.

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Chapter 4

CASE STUDY: LONG TERM CONSEQUENCES OF ATMOSPHERIC TESTS OF NUCLEAR WEAPONS AND CHERNOBYL DISASTER ON TERRITORY OF SOUTH BOHEMIA (CZECH REPUBLIC)

Diana Marešová[1,*], Eduard Hanslík[1,†], Eva Juranová[1,2,‡] and Barbora Sedlářová[1,§]

[1]Department of Radiology, T. G. Masaryk Water Research Institute, p.r.i., Prague, Czech Republic

[2]Faculty of Science, Institute for Environmental Studies, Charles University, Prague, Czech Republic

ABSTRACT

Temporal and spatial changes in concentrations of selected radionuclides (tritium, radiostrontium and radiocaesium) were assessed in the parts of the Vltava and Elbe river basins affected by the operation of the Temelín Nuclear Power Plant (Temelín plant). Construction and

* diana.maresova@vuv.cz.
† eduard.hanslik@vuv.cz.
‡ eva.juranova@vuv.cz.
§ barbora.sedlarova@vuv.cz.

subsequently operation of the Temelín plant initiated implementation of a number of projects, which were focused on possible impacts of the plant on the environment. The length of the series of the data that were monitored during the implementation of the projects is more than 20 years. Results of long-term monitoring (since 1990) were used for assessment of residual contamination from atmospheric tests of nuclear weapons in the last century and the Chernobyl accident. Concentrations of radionuclides were evaluated in surface water, sediments, fish and aquatic flora both affected and unaffected by waste water discharges from the Temelín plant before and during the operation of the plant. Effective ecological half-lives in surface water, sediments, fish and aquatic flora were derived. Apart of tritium the concentrations of anthropogenic radionuclides (^{90}Sr, ^{134}Cs and ^{137}Cs) downstream of the waste water discharge from the Temelín plant originate mainly from the residual contamination from atmospheric tests of nuclear weapons and the Chernobyl accident. In case of tritium the assessment was focused on an analysis of the results from sites unaffected by the Temelín plant where residual contamination from atmospheric tests of nuclear weapons was assessed.

Keywords: tritium, strontium 90, caesium 134, caesium 137, effective half-time, surface water, sediments

1. INTRODUCTION

Anthropogenic radionuclides in the territory of South Bohemia have been studied long because of the Nuclear Power Plant Temelín (Temelín plant).

The final decision to build the nuclear power plant Temelín dates back to year 1980. The construction started in 1987, and it has been in operation since 2001. Out of the intended four reactors only two have been completed and made operational so far. The original output of the plant's blocks was 2 x 1000 MW_e. The output was gradually increased to 1078 + 1055 MW_e (2014). Its further extension is currently being discussed. It is expected that the power output of the plant should be doubled. (CEZ Group, 2015).

Nuclear facilities represent point sources of assessed artificial radionuclides, however, while studying their impacts, it is also necessary to take into account the background of these radionuclides which is changing over time.

Temelín plant releases its waste water into the Vltava River. The Orlík reservoir, located on the Vltava River downstream of the waste water outflow, is presumed to play a major role in the radionuclides behaviour in the hydrosphere and it's outflow from assessed area.

Anthropogenic radionuclides have been observed in the environment since atmospheric tests of nuclear weapons and following the accident at the Chernobyl nuclear reactor in the last century. During the atmospheric tests of nuclear weapons 186.10^{3} PBq ^{3}H, 622 PBq ^{90}Sr a 948 PBq ^{137}Cs was released (UNSCEAR, 2000). The estimated amount of released radionuclides during the Chernobyl disaster is 10 PBq ^{90}Sr and 85 PBq ^{137}Cs (UNSCEAR, 2000).

According to Atlas (1998), the average surface deposition of ^{137}Cs due to Chernobyl disaster in the Czech Republic was 7.6 kBq/m^{2}. A comparison with other European countries is in Figure 1.

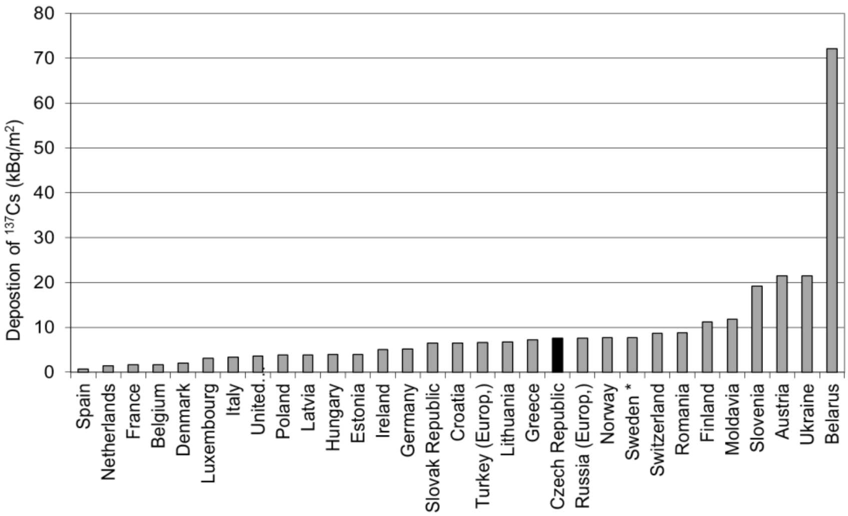

Figure 1. Average surface deposition of ^{137}Cs in European countries after the Chernobyl disaster in 1986 after according to Atlas (1998).

Estimates of the amount of ^{137}Cs deposited on the territory of the Czech Republic are based predominantly on investigations carried out in June 1986 by the Centre of Radiation Hygiene of the Institute of Hygiene and Epidemiology (IHE CRH, 1987). These investigations were later completed by aerial surveys (Gnojek et al., 1997) and a map of contaminated areas was created (Hanslík, 1998) (Figure 2). This map thus comprises even data from the atmospheric tests of nuclear weapons, estimated for 1986 by the UNSCEAR (2000) to be 1.9 kBq/m^{2} (cumulative deposition). The most seriously affected areas of our territory with surface deposition above 10 kBq/m^2 are towards the north-east to north-west, which corresponds to the wind direction at the time of the first appearance of the contaminated plume. The second and third plumes reached our territory from the south-east to north-west. The recorded ^{137}Cs volume activity in the Czech surface waters from May 1st to June 10th. 1986 ranged from 0.08 to 8.0 Bq/l (IHE CRH, 1987).

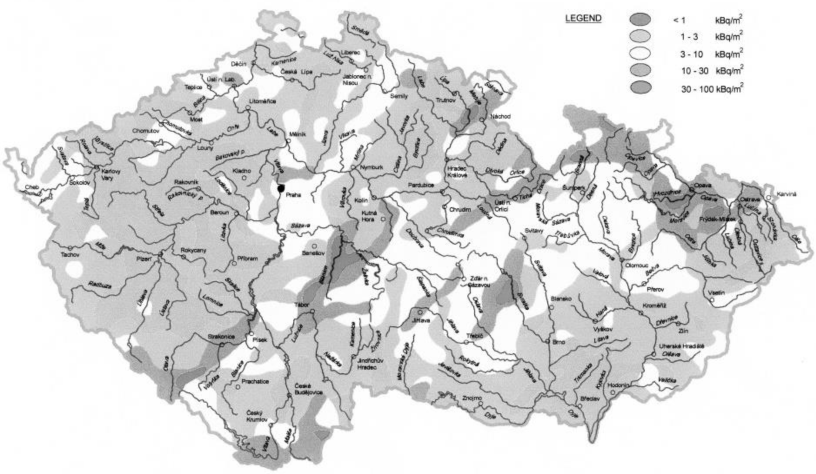

Figure 2. ^{137}Cs surface activity in soil (kBq/m^2) after the 1986 Chernobyl disaster, including ^{137}Cs data from nuclear weapon tests, according to Hanslík (1998).

The vicinity of Temelín plant ranks among regions afflicted by the first radioactive plume to arrive over our territory; according to IHE CHR (1987), fallout in this region reached 2.3 to 13 kBq/m^2. A detailed aerial survey was carried out in 1992 by Dědáček et al., (1992), subsequently specified by measurements in 1996 (Gnojek et al., 1997), and from both it follows that ^{137}Cs surface contamination around the power plant in 1996 was 1 - 16 kBq/m^2. These data would correspond with the 1986 fallout within 1.3 – 20.2 kBq/m^2.

However, ^{90}Sr fallout data after the disaster are very scarce, and official data on the total ^{90}Sr deposition had not been published. Due to a different character of the deposition, deposition estimates cannot be derived from the ratio of ^{90}Sr and ^{137}Cs in the reactor at the time of disaster, which was 0.12, as is the case of e.g., ^{134}Cs (Smith and Beresford, 2005). For example, according to Outola et al., (2009), the recorded ratio of ^{90}Sr and ^{137}Cs in the fallout over

Finland after the Chernobyl disaster ranged between 0.015 and 0.333. IHE CRH (1987) gives the ^{90}Sr and ^{137}Cs ratio in close-to-the-Earth atmospheric layer over Prague-Libuš in the range from 0.02 to 0.13. According to UNSCEAR (2000) estimates, ^{90}Sr contribution in 1986, i.e., the cumulative ^{90}Sr deposition from atmospheric tests of nuclear weapons, was 1.23 kBq/m^2.

The paper analyses the results of long-term monitoring and evaluates radionuclide concentrations in surface water and sediments in the vicinity of Temelín plant. Analysed radionuclides were tritium (^{3}H), strontium 90 (^{90}Sr) and caesium 137 (^{137}Cs).

Concentrations of radionuclides were evaluated in surface water, sediments, fish and aquatic flora both affected and unaffected by waste water discharges from Temelín plant before and during the operation of the plant.

The aim of the research was to quantify main components of radionuclide background stemming from natural (^{3}H) and anthropogenic processes (^{3}H, ^{90}Sr, ^{137}Cs; residual pollution from tests of nuclear weapons and Chernobyl disaster in the last century and the atmospheric transfer from nuclear facilities worldwide). The intention was to quantify radionuclide outflows and compared ^{90}Sr and ^{137}Cs activity outflow with their deposition.

2. Methods

Concentrations of ^{3}H, ^{90}Sr and ^{137}Cs were monitored in surface water (in both the dissolved and undissolved substances) and concentrations of ^{90}Sr and ^{137}Cs in sediments and complementarily in fish species and aquatic flora. Location of the sampling sites is shown in Figure 3.

Methods specified in Standards ČSN ISO 5667-1 (2007), ČSN ISO 5667-3 (2013), ČSN ISO 5667-4 (1994), ČSN ISO 5667-6 (2008) (national editions) were used for the sampling and sample processing. The surface water monitoring was launched in 1990 in the Vltava River at Hněvkovice, the Lužnice River at Koloděje and the Otava River at Písek, which are river sites located outside the impact of the Temelín plant (reference sites), and in the Vltava River at Solenice located downstream of the outflows from the plant. Since 1996, the monitoring was also carried out in the Vltava River at Hladná located about 4 km downstream of the waste water outflow. Frequency of the sampling was 4 samples a year. Further, more detailed monitoring of ^{3}H with the frequency of 12 samples a year was carried out at reference sites in the Vltava River at Hluboká and at the Elbe River at Lysá and at affected sites in the Vltava River at Podolí and at the Elbe River at Hřensko. Volumes of the water samples were 0.25 l for ^{3}H and 50 l for ^{90}Sr and ^{137}Cs. The samples for ^{3}H determination were stabilised by cooling while the large-volume samples were stabilised with nitric acid to pH below 2. The samples were dried by vaporization at temperature below boiling point and subsequently ignited (350°C) and closed into the measuring containers. The determination of ^{90}Sr and ^{137}Cs concentrations therefore includes both the dissolved and undissolved substances. Samples of water (1 l) for determination of total suspended solids (TSS) were taken with the same frequency (4 samples a year).

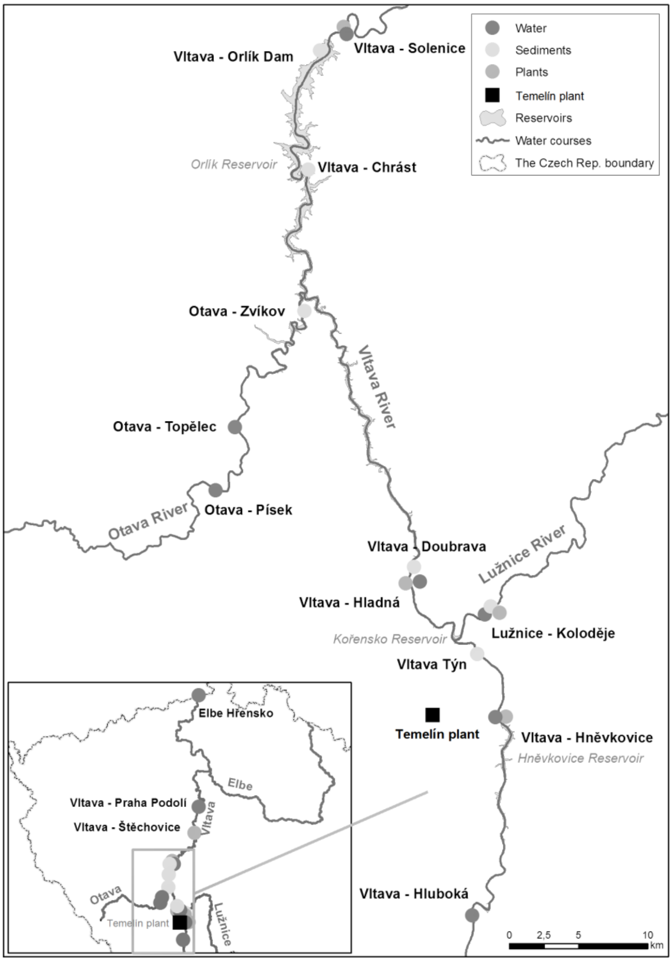

Figure 3. Map of the sampling sites.

The sediments, fish and aquatic flora have been monitored with frequency of one sample a year in both the reference and the affected sites. The sediment samples were taken from the top layer (0 – 10 cm) during the period of 1990-2014. The fish sampling was carried out during the period of 1986-1990, in 1994 and 1995 and then annually since 1998. The aquatic flora was sampled in the period of 1989-2014. The sampling included littoral species, aquatic mosses, algae species and submerged species.

The solid samples were transported in polyethylene boxes or bags. For the analysis, the samples were dried at 105°C. The samples of sediments were sieved and the fraction of less than 2 mm was analysed. The fish samples were disembowelled, weighted, pulped, dried and subsequently pulverised and locked in measuring containers. The analyses were performed for dry matter and the results were recalculated for fresh weight. The flora samples were cut into pieces and locked in measuring containers.

For determination of tritium activities, methods specified in ČSN ISO 9698 (2011) were used. The ^{3}H concentrations were determined by using Quantulus 1220 and TriCarb low-level liquid scintillation spectrometers. The relative efficiency of tritium measurement was 26%. The detection limit was set according to expected activities. For mixture of 8 ml of sample and 12 ml of scintillation solution and for counting time of 800 minutes (for samples not affected by the waste water discharges) or 300 minutes (for samples effected by the waste water discharges), the detection limit was 1.1 Bq/l and 2.1 Bq/l, respectively, at the level of significance of 0.05. Tritium in the analysed water samples from the reference sites has been pre-concentrated using electrolytic enrichment since 2012. The detection limit has been since then was 0.1 Bq/l.

Gammaspectrometric analysis was implemented to determine concentrations of ^{137}Cs by using methods specified in ČSN ISO 10703 (2008) and subsequently the ^{90}Sr concentrations were determined by using the method described by Hanslík (1993). A Canberra device was used for the gamma spectrometry. The minimum detectable activity (MDA) at the level of significance of $\alpha = \beta = 0.05$ of ^{137}Cs in water was 0.5 mBq/l, in the sediments 0.5 Bq/kg, in fish (wet weight) 0.1 Bq/kg. The ^{90}Sr activity was detected from the residue after igniting via detection of yttrium 90 after radiochemical separation. Value of MDA of ^{90}Sr was 3 mBq/l.

Trends in the concentrations of the radionuclides were analysed by using the following regression equation:

$$lnC_j = C_0 - \lambda_{eff} \cdot t \quad (1)$$

where C_j is annual average radioactivity concentration in year j, λ_{eff} is effective rate of decline in radioactivity concentration, calculated as the slope of decline line (1/y), t is time of the monitoring (y) and C_0 is natural logarithm of initial concentration.

Statistical significance of the regression line was verified by using the Pearson coefficient.

Then the effective ecological half-lives (T_{eff}) and the ecological half-lives (T_{ecol}) were calculated from the decrease in radionuclide activity according to the equation (Smith and Beresford, 2005):

$$T_{eff} = \frac{\ln 2}{\lambda_{eff}} \tag{2}$$

$$\frac{1}{T_{ecol}} = \frac{1}{T_{eff}} - \frac{1}{T_P} \tag{3}$$

where T_P is physical half-life (y).

The annual outflows of assessed radionuclides in Bq/y at individual sites were calculated as follows:

$$B_{R,j} = c_{R,j} \cdot Q_j \cdot t \tag{4}$$

where $c_{R,j}$ is annual radionuclide concentration in year *j* (Bq/m^3), Q_j annual average river flow in year *j* (m^3/s) and t is duration of a year in seconds.

The annual depositions of suspended solids ($D_{S,j}$) in a reservoir were calculated from the following equation:

$$D_{S,j} = \left(\sum_{t=1}^{n} c_{S,j,t}.Q_{j,t} + c_{S,j,ia}.Q_{j,ia} - c_{S,j,o}.Q_{j,o} \right) \cdot t.10^{-3} \tag{5}$$

where $D_{S,j}$ is deposition of suspended solids in a reservoir in individual years *(j)* (t/y), $c_{S,j,t}$ annual mean concentration of suspended solids *(j)* in individual tributaries (*t*) (kg/m^3), $c_{S,j,ia}$ annual mean concentration of suspended solids *(j)* in the inflow from inter-basin area (*ia)* (kg/m^3), $c_{S,j,o}$ annual mean concentration of suspended solids *(j)* in the outflow from a reservoir (kg/m), $Q_{j,t}$ annual mean inflow (*j*) from individual tributaries (*t*) (m^3/s), $Q_{j,ia}$ annual mean inflow *(j)* from the inter-basin area (m^3/s), $Q_{j,o}$ annual mean outflow *(j)* from a reservoir (m^3/s).

Similarly, based on the results of the ^{137}Cs activity monitoring in water (both the dissolved and suspended solids), the deposition of ^{137}Cs can be determined by the formula:

$$D_{A,137Cs,j} = \left(\sum_{t=1}^{n} c_{137Cs,j,t}.Q_{j,t} + c_{137Cs,j,ia}.Q_{j,ia} - c_{137Cs,j,o}.Q_{j,o} \right).t.10^{-9} \qquad (6)$$

where $D_{A,137Cs,j}$ is deposition of ^{137}Cs in individual years *(j)* (GBq/y), $c_{137Cs,j,t}$ annual mean activity of ^{137}Cs *(j)* in individual tributaries *(t)* of a reservoir (Bq/m), $c_{137Cs,j,ia}$ annual mean activity of ^{137}Cs *(j) in* the inflow from inter-basin area *(ia)* (Bq/m), $c_{137Cs,j,o}$ annual mean activity of ^{137}Cs *(j)* in the outflow from a reservoir in Bq/m.

Deposition of radionuclides in a given basin corrected on a decrease due to radioactive decay and outflow of radionuclide activity was calculated according to:

$$D_1 = D_0.e^{-\lambda.t} - B_1$$
$$D_2 = D_1.e^{-\lambda.t} - B_2$$
$$D_j = D_{j-1}.e^{-\lambda.t} - B_{j-1}, \qquad (7)$$

where D_{j-1} is the total radionuclide activity in a basin in the years j -1 (Bq/y), B_{j-1} annual balance of radionuclide activity at a river site in the years j -1 (Bq/y), as calculated from (4), λ decay constant of radionuclide (1/y), t duration of one year (s/y).

Radionuclide activity balance ($B_{rel.,j}$) related to total radionuclide activity in a given basin:

$$B_{rel.,j}[\%] = \frac{B_j}{D_j}.100 , \qquad (8)$$

where B_j is the annual balance of radionuclide activity at a river site in the year j (Bq/y) as calculated from (4), D_j total radionuclide activity in a basin in the year j (Bq/y) as calculated from (7).

3. Results and Discussion

3.1. Radionuclides in Surface Water

3.1.1. Tritium

Tritium concentrations in surface water were analysed separately at both the sites affected and the sites unaffected by the Temelín plant. For data from unaffected sites in the period of 1990-2014 (see Figure 4 A), Equation 1 gives effective ecological half-life of 15.8 y. The trend of decrease was statistically significant, but the calculated effective ecological half-life was longer than the physical half-life of tritium 12.32 y (Rozanski and Gröning, 2004). It is because apart from tritium form the atmospheric nuclear weapons tests relatively small tritium activities also originate from a constant component which results from cosmic radiation. The atmospheric transfer from nuclear facilities worldwide was also considered to be constant in the analysed period. These factors were therefore eliminated in subsequent analysis (Figure 4 B). The mean values were calculated by including tritium activities below the detection limit at the level of the limit. The annual average tritium activities ($c_{3HB,j}$) were corrected by subtracting its components originating from cosmic radiation (c_{3HCR}) and the atmospheric transfer from nuclear facilities worldwide (c_{3HNF}). After elimination of the constant components, which were appreciated 0.48 Bq/l according Hanslík et al., (1999), the effective ecological half-life (T_{eff}) calculated for the period of 1990-2014 was 10.0 y, which is shorter than that derived by using the first approach.

The component of tritium concentration originating from tests of nuclear weapons will be further decreasing and thus it can be assumed that the effective half-life will increase. After decomposition of tritium from tests of nuclear weapons, its concentration will include a constant component originating from cosmic radiation and a slowly increasing component stemming from atmospheric transfer of tritium from gaseous and liquid releases from nuclear facilities in the Czech Republic and abroad.

At sites (see above) unaffected by waste water discharges from the Temelín plant, the mean tritium activity calculated by using the first approach (the alternative not involving elimination of the constant components) was 3.1 Bq/l at the beginning of the analysed period (1990) and about 1.0 Bq/l at its end (2014).

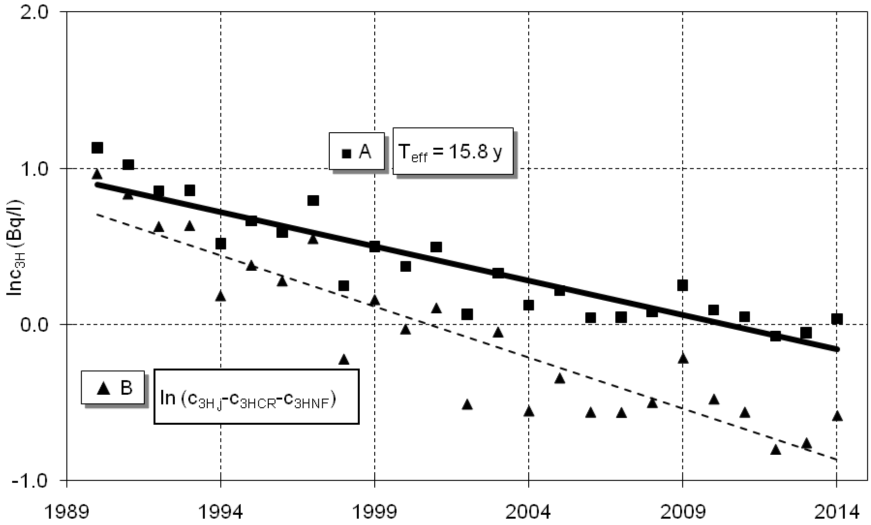

Figure 4. Annual average tritium concentrations in surface water unaffected by waste water discharges from the Temelín plant in the period of 1990-2014, without (A) and after correction (B) by subtracting the natural component and the activity originating from the atmospheric transfer from nuclear facilities worldwide.

The tritium concentrations in surface waters in the vicinity of the Temelín plant unaffected by waste water discharges are in accord with the results of observations performed abroad. Palomo et al., (2007) reported that tritium concentrations in samples taken in October 2005 and January 2006 in the vicinity of Asco Nuclear Power Plant (Spain) are between less than 0.6 and 0.93 Bq/l. The differences between the tritium concentrations in the vicinity of Temelín and Asco are not significant.

In contrast to the results derived for the unaffected sites, the trends in concentrations of ^{3}H at the affected river sites were remarkably different. Since 2001, when Temelín plant was put in operation, tritium concentrations in the Vltava and Elbe rivers downstream of the waste water outflow have been increasing. This is attributable to gradual increase in the output of the plant associated with increasing quantity of tritium. For the period of 2001-2014, annual average tritium concentrations in the Vltava and Elbe rivers are shown in Figure 5.

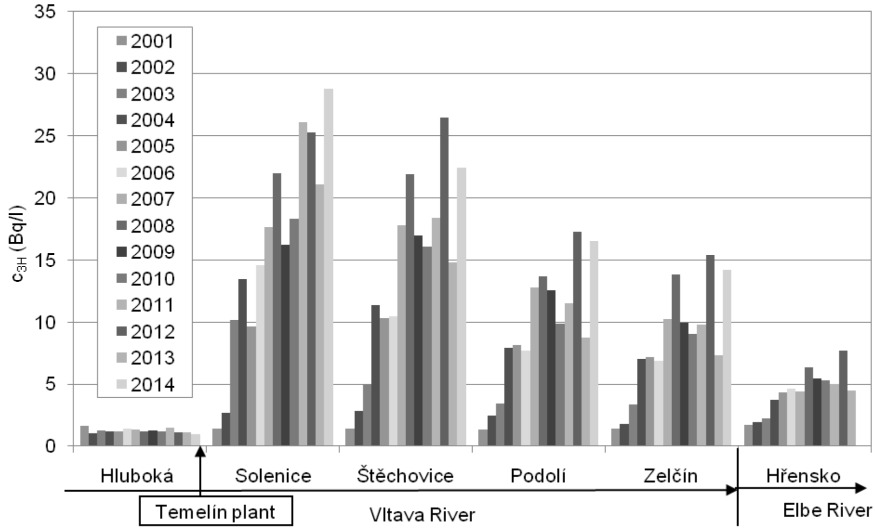

Figure 5. Annual average tritium concentrations in the Vltava River upstream (Hluboká) and downstream (the other sites) of the outflow of waste water from the Temelín plant.

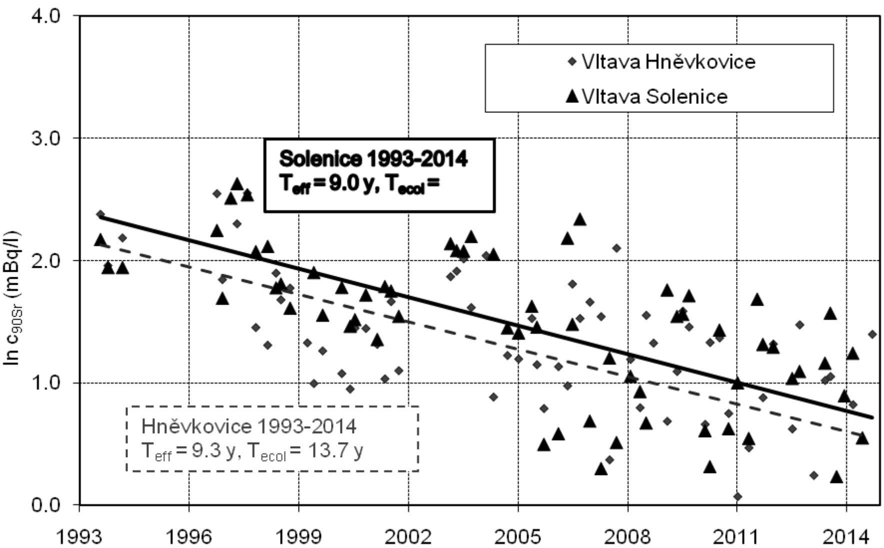

Figure 6. Temporal changes of [90]Sr concentration (c_{90Sr}) in the Vltava River at Hněvkovice (source of technological water) and the Vltava River at Solenice (downstream of the Temelín waste water outflow) in the period of 1993-2014.

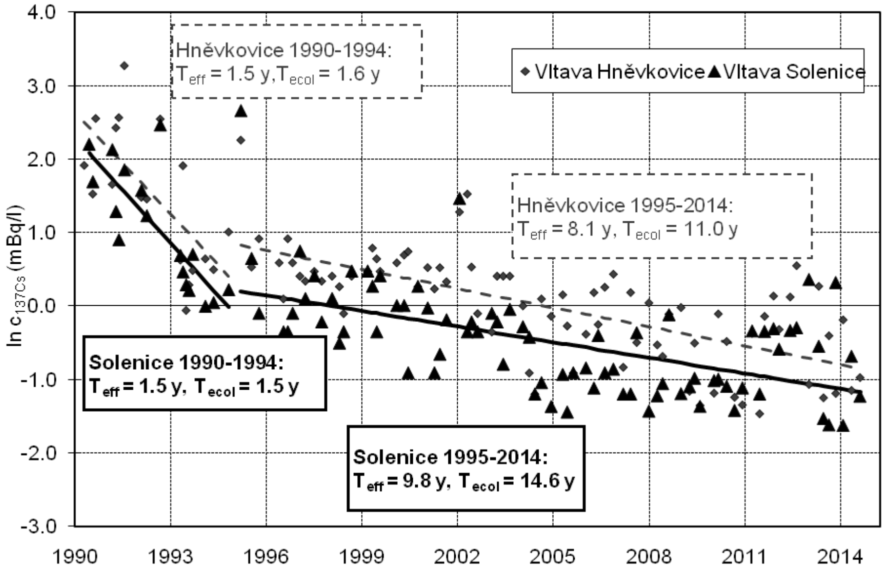

Figure 7. Temporal changes of ^{137}Cs concentration (c_{137Cs}) in the Vltava River at Hněvkovice and the Vltava River at Solenice in the periods of 1990-1994 and 1995-2014.

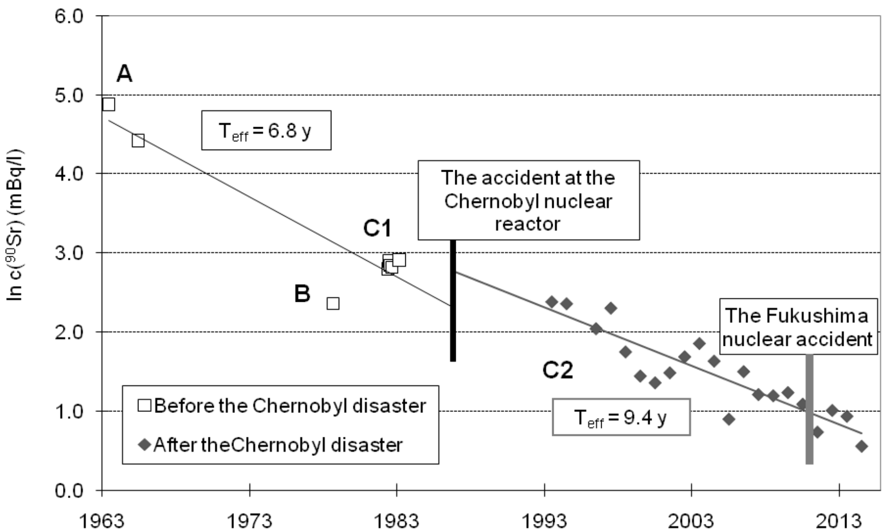

Figure 8. Time changes of ^{90}Sr concentration in the surface water in the periods 1963-1986 and 1993-2014, A - Vltava Prague-Podolí profile, B - Donau Expedition 1978, C - Temelín plant vicinity.

3.1.2. Strontium 90 and Caesium 137

Temporal changes of the ^{90}Sr concentrations in water samples taken from the Orlík reservoir and its tributaries were studied for the period of 1993-2014. The trend of decrease of the ^{90}Sr concentrations was observed over all of the assessed period. The effective ecological half-lives (T_{eff}) in individual tributaries and the outflow of the Orlík reservoir were in the range of 7.8-10.8 y and the ecological half-lives (T_{ecol}) were in the range of 10.7-17.2 y. An example is shown in Figure 6 for the Vltava River at Hněvkovice and the Vltava River at Solenice. In 2014, the average activity of ^{90}Sr at Hněvkovice (a reference site, source of technological water for Temelín plant) was 2.0 mBq/l and 2.2 mBq/l at Solenice (downstream of the Temelín waste water outflow).

Temporal changes of the ^{137}Cs concentrations in water samples taken from the Orlík reservoir and its tributaries were studied for two separate periods, 1990-1994 and 1995-2014. The effective ecological half-lives (T_{eff}) in individual tributaries and the outflow of the Orlík reservoir were in the range of 1.5-2.2 y for the period of 1990-1994 and 8.1-14.6 y for the period of 1995-2014. The ecological half-lives (T_{ecol}) were in the range of 1.5-2.4 y for the period of 1990-1994 and 11.0-28.1 y for the period of 1995-2014. An example is shown in Figure 7 for the Vltava River at Hněvkovice and the Vltava River at Solenice. In 2014, the average activity of ^{137}Cs at both sites was less than 0.7 mBq/l.

Our results showed that a decrease in the ^{90}Sr and ^{137}Cs concentrations, which was observed before the plant operation, also continued during the subsequent period.

The results of monitoring ^{90}Sr in the South Bohemia (Figure 8 C2) obtained in connection with Temelín plant were compared with data measured by T.G.M. WRI in the Vltava basin after the nuclear weapons tests (Figure 8 A), results of the Danube River expedition in 1978 (Figure 8 B) and further the results of the earlier monitoring in the Temelín plant vicinity from 1981-1984 (Figure 8 C1). In the first evaluated period after the nuclear weapons tests and before the Chernobyl accident, the observed half-life was 6.8 years; in the second period 1996-2014, after the Chernobyl disaster, it was 9.4 years. It can be concluded that effective ecological half-lives of ^{90}Sr observed after the nuclear weapons tests until the Chernobyl disaster and then after the Chernobyl are very similar.

Results of our research focused on the vicinity of the Temelín plant are in agreement with similar studies on changes in water contamination after the Chernobyl accident. For example, Zibold et al., (2001) showed a faster decrease of ^{137}Cs concentration in the period of 1986-1988 and a slower phase in 1989-2000. Similarly, Smith and Beresford (2005) reported that the rate of decline of the ^{137}Cs concentration in the Pripyat River was decreasing in recent years. The effective ecological half-lives of 1.2 years (dissolved phase) and 1.7 y (particulate phase) in the period of 1987-1991 increased to 3.4 y (dissolved phase) and 11.2 y (particulate phase) in the period of 1995-1998. This increase in T_{eff} has also been observed in Belarus, Ukraine and Finland (Zibold et al., 2001).

The concentrations of anthropogenic radionuclides ^{90}Sr and ^{137}Cs downstream of the waste water discharge from the Temelín plant therefore originate mainly from the residual contamination from atmospheric tests of nuclear weapons and the Chernobyl accident. These activities show a decreasing trend in time. The detected activities concentrations in surface water are currently near the detection limits.

3.2. Radionuclides in Sediments

The sediment monitoring was focused on concentrations of ^{90}Sr, ^{134}Cs and ^{137}Cs. Mean concentration of ^{90}Sr in the whole observed period (1993-2014) was 1.6 Bq/kg and 1.4 Bq/kg in 2001-2014 when Temelín plant was in operation. The assessment of ^{134}Cs was stopped in 1999 because starting this year, all observed values were below the MDA. Mean concentration of ^{134}Cs in the assessed period (1990-1999) was 5.6 Bq/kg. In 1990-2014, the mean concentration of ^{137}Cs in sediments was 67.6 Bq/kg and in 2001-2014, it was 31.3 Bq/kg. For the whole territory of the Czech Republic, the mean ^{137}Cs concentration in the period of 2000-2010 was 14.0 Bq/kg (Hanslík et al., 2014) which indicates that the sediments in the Orlík reservoir and its tributaries fall into those highly contaminated by ^{137}Cs in the Czech Republic.

The activities of these radionuclides are decreasing in time (Figure 9). The rates of decline are similar for the reference sites and the affected sites and therefore the trends of decline were evaluated for average annual activities from all observed sites. The effective ecological half-life for ^{90}Sr (for the period of 1993-2014) was 13.1 y and the estimated ecological half-life was 24.0 y. For ^{134}Cs (for the period of 1990-1999), the estimated effective ecological half-life was 1.6 y and the ecological half-life was 6.8 y. For ^{137}Cs, the effective half-life was 8.0 y for the period of 1990-2014. The estimated ecological half-life was 10.8 y.

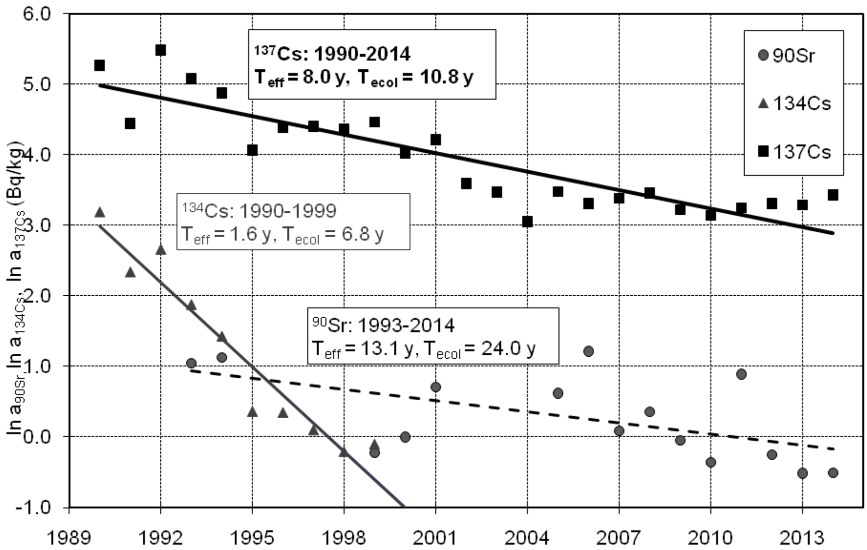

Figure 9. Temporal changes of annual average concentrations of ^{90}Sr (a_{90Sr}), ^{134}Cs (a_{134Cs}), and ^{137}Cs (a_{137Cs}) in sediments (dry matter) in the Orlík reservoir and its main tributaries in the periods of 1993-2014 (^{90}Sr), 1990-1999 (^{134}Cs) and 1990-2014 (^{137}Cs).

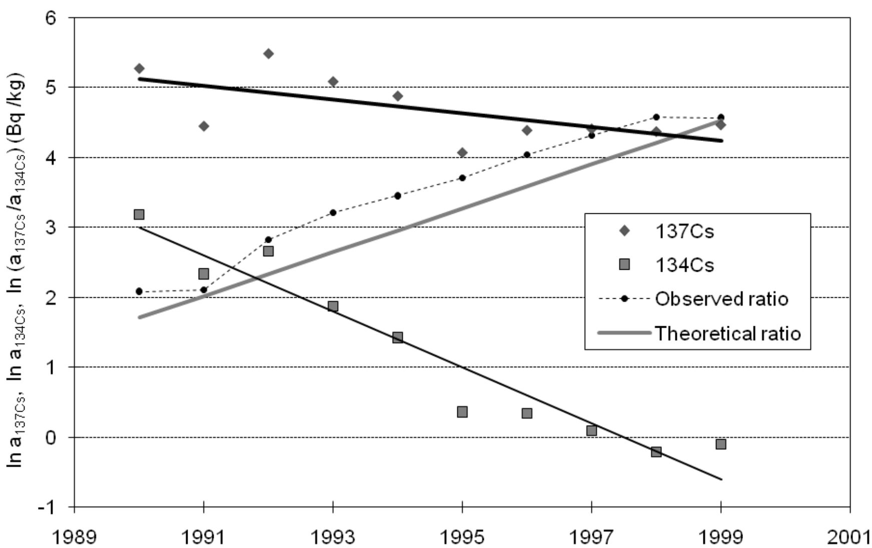

Figure 10. Time changes in annual average concentration of ^{137}Cs (A1) and ^{134}Cs (A2) in the bottom sediments in the Orlik Reservoir and their ratio, calculated from observed data and from the ratio during Chernobyl accident.

Figure 10 shows comparison of ^{137}Cs and ^{134}Cs concentrations ratio calculated from observed data and theoretical trend of ^{137}Cs and ^{134}Cs concentrations ratio, which was derived from released activities during the Chernobyl accident (85 PBq ^{137}Cs and 54 PBq ^{134}Cs, according UNSCEAR, 2000). We can conclude that dominant part of radiocaesium contamination comes from Chernobyl disaster and minor part from atmospheric tests of nuclear weapons.

Apart from ^{90}Sr, ^{134}Cs (until 1999), and ^{137}Cs, the results of the monitoring did not substantiate sediment contamination by any other activation and fission products detectable by gammaspectrometric analysis or ^{90}Sr determination.

3.3. Radionuclides in Fish and Aquatic Flora

The monitoring of fish and aquatic flora focused on concentrations of ^{90}Sr and ^{137}Cs.

The concentrations of ^{90}Sr in fish were assessed for the entire observation period of 1990-2014. For this period, the mean ^{90}Sr concentration in fish was 0.6 Bq/kg. Relatively rare data and information on ^{90}Sr concentrations in fish include (Outola et al., 2009), where it was reported that in the period of 1978-1997 the concentrations in the analysed river species were in the range of 10-17 Bq/kg, which exceeded the ^{90}Sr concentrations in fish from the Orlík reservoir by approximately one order of magnitude. The concentration of ^{90}Sr were however smaller by several orders of magnitude as compared to those of ^{137}Cs. Most of the ^{90}Sr activity is accumulated in bones and thus ^{90}Sr is less dangerous than ^{137}Cs in terms of radioactive doses originating from food chain (Outola et al., 2009).

The concentrations of ^{137}Cs in fish (related to fresh weight) were assessed for the periods of 1986-1990 and 1994-2014. Between the two periods, the ^{137}Cs concentrations decreased from 2.45–47.9 Bq/kg (1986-1990) to 0.05–2.35 Bq/kg (1994-2014). The results of the monitoring and assessment of the ^{90}Sr and ^{137}Cs concentrations in fish are illustrated in Figure 11. The concentrations in the Czech Republic are substantially lower than those in the areas most affected by the Chernobyl accident. Those activities were at levels of hundreds of kBq/kg shortly after the accident and in the early 1990's remained at levels of dozens of kBq/kg. The activities of several Bq/kg were reported from Switzerland, England or Germany in this period (Smith et al., 2000).

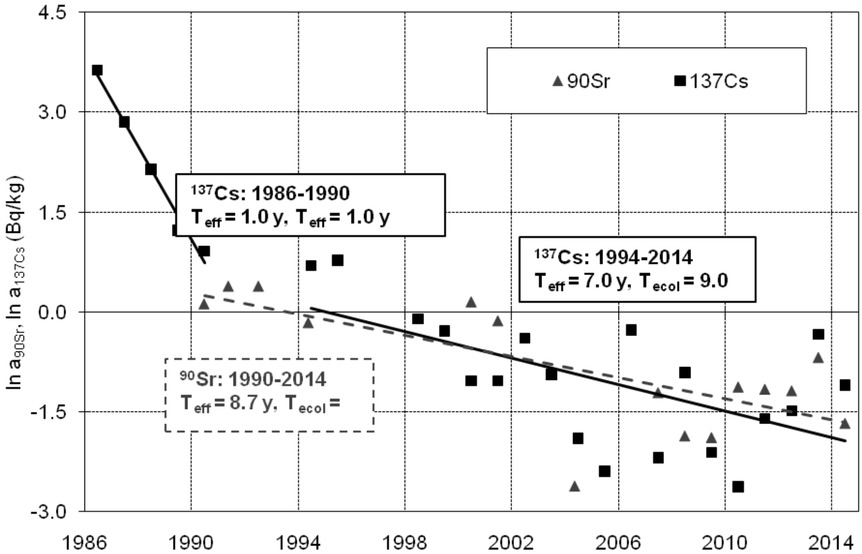

Figure 11. Temporal changes in ^{90}Sr and ^{137}Cs concentrations (a_{90Sr}, a_{137Cs}) in fish (wet weight) in the Orlík reservoir in the periods of 1990-2014 (a_{90Sr}) and 1986-1990, 1994-2014 (a_{137Cs}).

In accord with the results derived for surface water (and sediments), the concentrations of ^{90}Sr and ^{137}Cs in fish exhibited a decreasing trend. The evaluated effective ecological half-life (T_{eff}) for ^{90}Sr was 8.7 y and the ecological half-life (T_{ecol}) was 12.5 y for the period of 1990-2014. The effective ecological half-times derived for several fish species in Finnish lakes were between 7 and 30 y (Outola et al., 2009).

For ^{137}Cs the evaluated half-lives were shorter than for ^{90}Sr. The effective ecological half-lives were 1.0 y for the period of 1986-1990 and 7.0 y for the period of 1994-2014. The ecological half-lives were 1.0 y and 9.0 y respectively. Identical results were reported by Franić and Marović (2007) from observation in Croatia in the period of 1987-1992, while this decrease exceeded that derived by Smith et al., (2000) for identical period. The reported half-times are between 2 and 3 y. In accord with the results from the Czech Republic, the literature shows that the decrease in the following period was significantly declining towards that expressed by physical half-time. The effective ecological half-times in Finnish lakes were between 3 and 6 y (Outola et al., 2009). Franić and Marović (2007) reported 5 y for the period of 1993-2005. The ^{137}Cs half-times that were derived for fish correspond to those derived for water. The decreasing trend also continued during the operation of the Temelín plant.

Concentrations of ^{90}Sr and ^{137}Cs were also monitored in aquatic flora. Concentrations of ^{137}Cs were monitored for several aquatic flora species (in dried matter). The results substantiated an assumption that the highest ^{137}Cs concentrations were accumulated in a group of aquatic mosses (21.8 Bq/kg in 1996) and algae (17.9 Bq/kg in 1996). Comparison of the results from both the river sites unaffected and the ones affected by the outflow from the Temelín plant was complicated by different plants growing at the individual sites, with the exception of reed species. Since 2006, the monitoring was therefore focused on these species, which were also used for the assessment. The results of the assessment show that concentrations of ^{137}Cs in the reed species decreased with the effective ecological half-time of 11.4 y and the ecological half-life of 18.4 y for the period of 1996-2014. The decreasing trend was identified for the unaffected as well as for the affected river sites and continued in the period when the Temelín plant was in the operation. ^{90}Sr concentration in reed species was in the range of 0.5 and 6.1 Bq/kg (in dried matter) and this concentration decreased with the effective ecological half-time of 6.5 y and the ecological half-life of 8.4 y.

3.4. Assessment of Radionuclides Outflows

Data on river flows and concentrations of suspended solids, ^{137}Cs and ^{90}Sr were used to assess possible impacts of the Orlík reservoir on monitored matters.

Annual mean concentrations of suspended solids in samples from the Orlík reservoir and its tributaries were used together with annual mean flows for evaluation of a relationship between suspended solids deposition in the Orlík reservoir and annual mean flow. Subsequently, it was calculated that the annual deposition of suspended solids ranged between 71.3% – 95.3% (with the average value of 85.8%) of the inflow of the suspended solids. In units of mass, the annual mean deposition is 30 200 tons. The deposition of suspended matter in the Orlík reservoir expressed in percentages did not show any time dependence.

The annual deposition of ^{137}Cs was determined to be between 36.0% and 75.7% (1.0 – 19.2 GBq/y) with the average value of 61.9%. The annual deposition of suspended solids (SS) and ^{137}Cs are presented in Figure 12. The annual deposition of ^{137}Cs decreased in correlation with the effective ecological half-life of 9.4 years (in the period 1990-2014). The temporal trend of decrease is in accord with the observed trends in ^{137}Cs activity in water and sediments in the area of study. The mean percentage of ^{137}Cs deposition was lower than that of the suspended solids. This result indicates that a fraction of ^{137}Cs concentration was dissolved in water while its deposited fraction was fixed on solid particles.

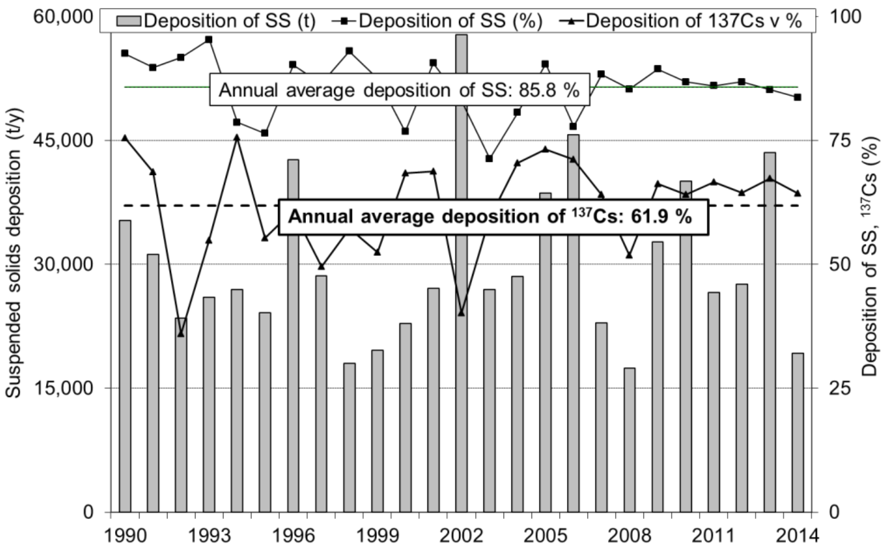

Figure 12. Annual deposition of suspended solids (SS) and ^{137}Cs (deposited SS expressed in tons and percentages and deposited ^{137}Cs expressed in percentages in the period of 1990-2014).

The analysis of ^{90}Sr concentrations showed that the outflow of ^{90}Sr from the Orlík reservoir exceeds the inflow of ^{90}Sr from the tributaries and the inter-basin area. The percentage outflow of ^{90}Sr was detected in the range from -37.8% to 72.1% with the average value of 19.8%.

Similar ^{137}Cs accumulation was reported for a cascade of reservoirs constructed on the Dnepr River (IAEA, 2005) or for the lakes Lago di Lugano and Lago di Maggiore in Switzerland and Italy. The ^{137}Cs concentrations in the upper lake (Lago di Lugano) permanently exceed those of the lower lake (Lago di Maggiore) by one or two orders of magnitude (Putyrskaya, 2009). Accumulation of ^{90}Sr in reservoirs was not substantiated (IAEA, 2005). During some periods, ^{90}Sr can even remobilize and discharge from a reservoir, which was also substantiated for the Orlík reservoir, whose mean ratio between the inflow and outflow of ^{90}Sr activities was 0.90.

The ^{90}Sr and ^{137}Cs activity outflow was compared and with their deposition. Outflows were assessed in relation to their activities deposited in separate river basins due to the Chernobyl disaster and the fallout after the atmospheric nuclear weapons tests. These assessments refer to years 1986 – 2014.

The estimated deposition of ^{137}Cs over the river sites in question was based on maps of surface ^{137}Cs activity in soil as drawn after the Chernobyl disaster (Figure 2). The ^{90}Sr deposition estimate made use of ^{137}Cs deposition estimates and measurements carried out after the disaster. The estimated ^{137}Cs deposition over every single monitored river basin, inclusive of the ^{137}Cs contribution to these river basins due to atmospheric nuclear weapons tests, amounted to 31.8 TBq (the Vltava to Hněvkovice), 24.9 TBq (the Lužnice in Koloděje), 28.6 TBq (the Otava in Písek), making it a total of 86.1 TBq for the whole Vltava River basin as far as to Solenice. Inter-basin contributed by approximately 0.75 TBq. In the case of mere physical decay of ^{137}Cs, the present activity (i.e., activity at the end of 2014) of individual basins would amount to 16.5 TBq (Vltava – Hněvkovice), 12.9 TBq (Lužnice – Koloděje), 14.8 TBq (Otava – Písek), and 0.4 TBq (inter-basin), i.e., 44.5 TBq in total.

Official data on the total ^{90}Sr deposition after the Chernobyl disaster had not been made public, and so the ^{90}Sr deposition estimates for the river basins in question made use of data on ^{137}Cs activity deposition according to the ratio of ^{90}Sr to ^{137}Cs in the ground level of the atmosphere as well as of the ^{90}Sr contribution (i.e., the cumulative ^{90}Sr deposition due the tests of nuclear weapons until 1986) estimated by UNSCEAR (2000) to be 1.23 kBq/m^2. The measurements were taken in Prague-Libuš, and according to IHE CRH (1987) the ratio ranged from 0.02 to 0.13, i.e., 0.076 on the average. The data were as follows: 7.18 TBq (the Vltava – up to Hněvkovice), 7.10 TBq (the Lužnice in Koloděje), and 6.89 TBq (the Otava in Písek), making it a total of 21.4 TBq ^{90}Sr for the whole Vltava River basin as far as Solenice. The value for inter-basin was thus approximately 0.20 TBq, the total being 10.8 TBq. In the case of mere physical decay of ^{90}Sr, the present activity (i.e., activity at the end of 2014) of individual basins would amount to 3.54 TBq (Vltava – Hněvkovice), 3.5 TBq (Lužnice – Koloděje), 3.4 TBq (Otava – Písek), and 0.1 TBq (inter-basin).

Assessments were made of ^{90}Sr and ^{137}Cs activity outflow at individual basins referred to the activities deposited in respective river basins in 1986. To assess the period of 1986 – 1989, use was made of values of c_{90Sr} and c_{137Cs}

obtained by calculations (i.e., extrapolated from) the 1990-1994 decrease characteristics. ^{90}Sr and ^{137}Cs deposition was calculated as corrected to its decrease due to radioactive decay and radionuclide activity outflow (D) according to (7), and then also the radionuclide activity balance ($B_{rel.,j,}$ according to 8) referred to the total activity of the radionuclide in the respective river basin.

In the Vltava-Hněvkovice river basin, the annual outflow (balance) of ^{90}Sr calculated in the individual river basins reached 0.100% of the average of ^{90}Sr activity, i.e., 0.024 – 0.226%. In the following basins the average figures were as follows: Lužnice-Koloděje 0.101% (i.e., 0.029 – 0.311%), Otava-Písek 0.083% (i.e., 0.020 – 0.184), and Vltava-Solenice 0.126% (i.e., 0.037 – 0.304%). By the end of 2014 ^{90}Sr activity outflow over the territory of the whole Vltava-Solenice basin represented 3.6%.

At Vltava-Hněvkovice, the average calculated annual activity outflow (balance) of ^{137}Cs $B_{rel.,j}$ of individual river sites represented 0.022% (i.e., 0.002 – 0.161%) of the ^{137}Cs activity in the river basin; at the Lužnice-Koloděje site it was 0.025% (i.e., 0.004 – 0.195%), at the Otava-Písek site 0.105% (i.e., 0.004 – 0.949%), and at the Vltava-Solenice site 0.017% (i.e., 0.002 – 0.146%). Contribution of the ^{137}Cs activity outflow to the total decrease in ^{137}Cs in the given area was minimal. By the end of 2014 it was only 0.49% for the whole area being monitored, i.e., the Vltava at Solenice.

According to a similar evaluation by Erlinger et al., (2009), in small selected river basins in the Austrian Alps, in 2005 the annual outflow of ^{137}Cs ranged from 0.0008 to 0.0031%, on the average 0.002%. After Garcia-Sanchez (2008), ^{137}Cs activity outflow represented only a minor contribution to the total ^{137}Cs activity decrease in the basin. The calculated ^{137}Cs activity outflow in this area was lower by one order than of ^{90}Sr. ^{90}Sr deposition into sediments is considerably slower than the uptake of ^{137}Cs. Also Saxén and Ilus (2001) report that ^{90}Sr outflow from an area was more significant than of ^{137}Cs.

CONCLUSION

Concentrations of anthropogenic radionuclides downstream of the wastewater outflow from the Temelín plant are mainly due to the residual contamination from global fallout and the Chernobyl accident. The influence of the Temelín plant on concentration of the activation and fission products in the hydrosphere (apart from tritium) has been negligible. Downstream of the plant, significantly higher tritium activity concentrations were detected, corresponding to the tritium discharged from Temelín plant.

For all of the components of the environment, concentrations of ^{90}Sr and ^{137}Cs, which were used for calculation of their effective and ecological half-times, decreased. The rate of decrease in ^{90}Sr concentration was invariable during the whole assessed period of 1993-2014. For ^{137}Cs in surface water and fish, the rates of decrease in the first and second monitoring period were different (1990-1994 and 1995-2014). Concentrations of ^{3}H at sites unaffected by the Temelín plant decreased slowly and their values were substantially below those from the sites affected by the plant. The effective ecological half-life calculated for the period of 1990-2014 was 15.8 years or 10.0 years after subtraction of the natural tritium component and the tritium originating from the atmospheric transfer from nuclear facilities worldwide.

Annual suspended solids, ^{90}Sr and ^{137}Cs outflows were derived from obtained data. The results of the monitoring showed that 86% of suspended solids and 62% of ^{137}Cs inflowing into the Orlík reservoir accumulate in the reservoir while accumulation of ^{90}Sr was not substantiated.

The outflow of ^{90}Sr and ^{137}Cs activities was also appraised, being related to the activity of radionuclides deposited in individual river basins of the Orlík reservoir tributaries due to the Chernobyl disaster and fallout after atmospheric nuclear weapons tests. At all river basins of the Vltava, the Lužnice, and the Otava as far as the Vltava-Solenice site, the total ^{90}Sr outflow between 1986 and 2014 represented only 3.6% of the deposited ^{90}Sr activity. The calculated outflow of ^{137}Cs activity was approximately one order lower than of ^{90}Sr. For the whole monitored territory, i.e., the Vltava at Solenice, until 2014 it amounted only to 0.49%.

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Chapter 5

STRESS ADAPTATION OF MICROSCOPIC FUNGI FROM AROUND OF CHERNOBYL ATOMIC ENERGY STATION

Tatiana Belozerskaya [*] ***and Natalya Gessler***
A. N. Bach Institute of Biochemistry, Federal Center of Biotechnology, Russian Academy of Sciences, Moscow, Russia

ABSTRACT

Specialized fungi have been isolated in and around the remains of the Chernobyl atomic energy station (ChAES). To cope such environment these fungi worked out resistance mechanisms such as asexuality**,** synthesis of melanin like pigments, flexible morphology, and growth under limited nutrient content in the habitat. Multitrophic in nature, they possess high phenotypic plasticity. Adaptation of *Purpureocillium lilacinum* ChAES strains to low glucose (0.2%) in the medium was coupled with an increased resistance to oxidative stress. It seems to be a consequence of metabolic adaptation, and a result of melanin pigments protection. These traits might be a result of genome variations important for elucidation of stress-response elements and for understanding the evolution of extremophiles.

Keywords: ChAES microfungi, Purpureocillium lilacinum, oxidative stress resistance

[*] E-mail: tabinbi@mail.ru.

INTRODUCTION

Proper adaptation to stress is critical for cell survival. The kingdom Fungi possesses powerful tools for environmental stress sensing, signaling and adaptation. Hence, they can occupy versatile ecological niches. Microfungi (anamorphs, producing conidiospores) represent an extensive group of organisms in a soil. They have been isolated in and around the remains of the ChAES where radiation dose was from 3 to 5 orders higher than the background radioactivity. They appear to be highly resistant to radionuclides in the environment. ChAES microfungi have been shown to take up and translocate in the mycelium a waste array of naturally occurring as well as man-made radionuclides. Dead mycelia (cell walls) made into filters have been used to adsorb heavy metals and radionuclides from industrial effluents. Absorption of radionuclides by fungi seems to be strain-specific [1].

Radioresistance of fungi is apparently determined by bringing into action several mechanisms: energetic metabolism change, ROS-defense systems, pigments, DNA-repair systems, etc. [2-4].

About 40% of all fungi isolated from the Chernobyl 4th block reactor also contained melanin and, possibly other pigments [1]. These noticeably exceeded the ratio of melanin-containing fungi, found in environments with background radioactivity. The most frequently occurring pigmented species were C. sphaerospermum, C. herbarum, H. resinae, A. alternata, and A. pullulans [1]. Melanin has been shown to account for between 45% and 60% of ^{60}Co and ^{137}Cs incorporation into fungal hyphae [5]. Thus melanized fungi are proposed to be good candidates in bioremediation, since the organisms can potentially bind radionuclides and many other toxic substances. The correlation of fungal species dominance with radiation level was established, despite differences in the habitat between sampling sites [6]. Together with Chaetomium aureum, Purpureocillium lilacinum is one of the indicators of high levels of radionuclide soil contamination (3.7 x 10^6–3.7 x 10^8 Bq/kg) in ChAES zone [1].

The authors place special emphasis on strains of Purpureocillium lilacinum (Paecilomyces lilacinus) (Thom) Luangsa-ard, Hou-braken, Hywel-Jones and Samson (2011) – a representative of imperfect fungi (Fungi imperfecti), naturally occurring fungus found in many kinds of soils throughout the world. Different isolates of P. lilacinum were also found to exhibit parasitic or endophytic lifestyles [7]. These species are known to produce a diversity of the secondary metabolites [8]. They are multitrophic in nature and several morphological forms have been observed (pellets, biofilms, filaments) [9, 10]. Thus, these fungi possess high phenotypic plasticity.

Though they were among the light-colored fungi, P. lilacinum strains from radionuclide-contaminated soils had melanin content about 2-2.5 times higher than its content in related strains isolated from the areas with background radioactivity [11]. The occurrence of melanized fungi in the areas with high levels of radiation undoubtedly reflects their advantage relative to nonmelanized species. Fungal melanin subjected to ionizing radiation showed changes in ESR signal, which consists with changes in electronic structure. Irradiated melanin showed an increase by four in the capacity to reduce NADH relatively to nonirradiated one [12]. Gamma radiation-induced oxidation of melanin resulted in electric current production, especially in the presence of a reducing agent [13]. These properties apparently explain the increased metabolic activity and enhanced growth of fungal hyphae under different types of radiation, found in melanin-containing fungi [3, 12]. Observations of enhanced growth of melanized fungi under low-dose ionizing radiation in the laboratory and in the damaged Chernobyl nuclear reactor suggest that they have adapted the ability to survive or even benefit from exposure to ionizing radiation [3, 12]. Thus, the participation of melanin in active electron transport in living cells leads to a hypothetical mechanism of radiation energy utilization for the increase in metabolic activity. Further research in this area can provide a better understanding of the nature of the radio- and UV-protective effect of melanin.

The mechanisms whereby fungi arrive at sources of radionuclides in the environment are poorly understood. There has been considerable interest in the interaction of fungal cells with radionuclides in the environment. ChAES fungi growing over and decomposing radioactive ‘hot’ particles, containing not only ^{137}Cs, ^{121}Sr and ^{152}Eu, but also such radioisotopes as ^{239}Pu and ^{241}Am [1, 14], indicated the presence of preferential growth of some fungal species towards the particle (radiotropism) as a response to radiation [14, 15]. Increase in spore germination rate was also observed in the ChAES microfungi under both beta and gamma radiation. Authors proposed that these properties could be important in controlling the decomposition of radionuclide-bearing particles in the environment [16].

To elucidate mechanisms of ChAES fungi biological activity the new approaches must be considered. Ionizing radiation injuries of biopolymers are induced by the direct effect of ionizing radiation and, in large part, by the attack of short-lived reactive oxygen species (ROS) resulting from water radiolysis. Hydrogen peroxide, the most long-lived transformation product of

ROS, influenced elongation rate of fungal hyphae [10]. On the basis of these experiments a phenomenological model of fungal colony growth has been suggested to analyze dynamics of the development of mycelial fungi colonies in a hydrogen peroxide gradient created by a local source of ionizing radiation. Model allows estimate the influence of H_2O_2 spatial distribution on colony form during fungal growth and expansion [17].

The growth of fungi isolated from the ChAES zone markedly declined at H_2O_2 medium concentration of about 10^{-1}-10^{-2} M. On the other hand, fungi from habitats with background radioactivity ceased their growth under 10^{-3}-10^{-4} M H_2O_2. Thus, P. lilacinum ChAES strains possess increased resistance to oxidative stress as well as some other microfungi of ChAES zone [10, 18]. High resistance to oxidative stress in ChAES strains in comparison to strains from background radioactivity habitats was demonstrated through H_2O_2-induced protein carbonylation, especially when grown in low glucose (0.2% glucose in the medium) [4]. On the other hand, under low glucose concentrations (0.1% - 0.5%), a profound increase in radial growth rate of P. lilacinum from around Chernobyl relatively to the growth of strains from habitats with background radioactivity was found [18]. Thereby, it was revealed that under 0.2% glucose ChAES strains were appreciably more resistant to oxidative stress than strains from unpolluted soils.

It seems to be a consequence of metabolic adaptation, thus providing support for ubiquity of the oligotrophic lifestyle in extremophylic fungi [2].

In fact, efficiency of glucose utilization (in low glucose) appeared to be higher in strains from polluted territories than in the control ones [18]. The differences in the rates of oxygen consumption, activities of the main respiratory pathway of electron transfer and alternative respiration point to adaptive rearrangement of glucose assimilation in the radiation resistant strain [4]. These data represent glucose metabolism peculiarities upon its variations in the growth medium in the strains isolated from habitats with various radioactivity. Metabolic adaptations increasing the capacity of glucose utilization of melanin-containing Chernobyl strains in low glucose growth conditions apparently provide their oxidative stress-resistance allowing fungi to survive under increased radiation.

CONCLUSION

The ChAES strains revealed an increased resistance to oxidative stress in comparison to the strains from background radioactivity habitats as a result of lowered glucose concentration in a medium. Each of the carbon utilization pathway upon growth in high or low glucose has apparently its own characteristics that are related to the habitat of the strain tested. They differ in their energy budget and in their sensitivity to peroxide. The olygotrophic lifestyle of the ChAES strains puts forward various system of glucose utilization and apparently unusual sources of energy and carbon used. It is tempting to speculate how radiation of different wavelengths could be transformed into biochemical energy. The possible role of melanin has already been mentioned above. The different ways of CO_2 fixation and acceptance of volatile compounds can also be considered.

Unfortunately the obtained data are still not enough to create complete description of the mechanisms, providing tolerance and adaptation of studied microorganisms to radiation. Comparative genomics of P. lilacinum ChAES strains tested and the strains from background radioactivity zones can be used to assess mutation patterns associated with radionuclide soil contamination.

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BIOGRAPHICAL SKETCH

Tatiana Belozerskaya, PhD
A. N. Bach Institute of Biochemistry,
Federal Center of Biotechnology,
Russian Academy of Sciences

Education: Lomonosov Moscow State University, Moscow, Russia

Address: Bach Institute of Biochemistry,
Research Center of Biotechnology of the Russian Academy of Sciences,
33, bld. 2 Leninsky Ave.,
Moscow 119071, Russia

Research and Professional Experience: 1972 –PhD;
1995 Doctor of Science;

Scientific interests: Filamentous fungi, growth, differentiation, cell membranes, intrahyphal communication, signal transduction, secondary metabolites, stress-defence responses, oxylipins.

Professional Appointments: Doctor of Science, Leader Reseach Worker: Bach Institute of Biochemistry;

Professor of Biological Department, Moscow State University

Honors: A medal “Biotechnology world” Presented for scientific research results on oxidated polyunsaturated fatty acids as regulators of fungal development, 2011

Publications Last 3 Years:

[1] Belozerskaya Tatiana, Gessler Natalya, Aver’yanov Andrey. Melanin pigments of fungi. Book chapter in Reference Series in Phytochemistry: Fungal metabolism. Springer Books. 2015.

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Natalya Gessler, PhD

A. N. Bach Institute of Biochemistry,
Federal Center of Biotechnology,
Russian Academy of Sciences

Education: K. I. Skryabin Moscow State Academy of veterinary, medicine and biotechnology

Address: Bach Institute of Biochemistry,
Research Center of Biotechnology of the Russian Academy of Sciences,
33, bld. 2 Leninsky Ave., Moscow 119071, Russia

Research and Professional Experience: 1988 – PhD

Scientific interest: melanins, oxylipins

Professional Appointments: Senior Research Scientist

Publications Last 3 Years:

[1] Belozerskaya Tatiana, Gessler Natalya, Aver'yanov Andrey. Melanin pigments of fungi. Book chapter in Reference Series in Phytochemistry: Fungal metabolism. Springer Books. 2015.

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Chapter 6

RADIATION AND RISK OF HEMATOLOGICAL MALIGNANCIES IN THE CHERNOBYL CLEAN-UP WORKERS: A REVIEW OF RECENT LITERATURE SHORT COMMUNICATION

Jon-Magnus Tangen*

Norwegian National Unit for CBRNE Medicine,
Oslo University Hospital, Nydalen, Norway

ABSTRACT

A summary of epidemiological studies addressing the cancer risk after the Chernobyl accident was presented in the United Nations Chernobyl Forum Report of 2006. The main finding was a dramatic increase in the incidence of thyroid cancer in children living in radiologically contaminated areas in Ukraine, Belorus and Russia. Furthermore, on the grounds of results from population based epidemiological studies, an increased risk of leukemia and other hematological malignancies among the 600,000 Chernobyl clean-up workers (or "liquidators") was suggested. However, firm conclusions could not be drawn because of uncertainties inherent in the study designs. After the publication of the Chernobyl Forum Report three new major

* Tel: +4793011699, E- mail: uxjmta@ous-hf.no.

epidemiological investigations have been published, one cohort study and two nested case-control studies, which also conclude with an increased leukemia incidence in the Chernobyl liquidators. The aim of the present report is a critical review of these new studies.

INTRODUCTION

The massive release of radioactive material at the Chernobyl accident in 1986 led to widespread radiation exposure, in particular to people evacuated from the settlements near the reactor and workers involved in the clean-up operations, and also to several millons living in contaminated regions in Russia, Belorus and Ukraine [1]. The carcinogenic effect ionizing radiation in the higher dose ranges is well documented, in particular from the Life Span Study among Japanese atomic bomb survivors [2]. A possible relationship between cancer and radiation with lower dose rates or lower total doses is less well established, but has been shown in some studies, notably in the population living near the radioactively contaminated Techa River in the Urals, Russia [3, 4]. The question of an increased risk of malignancy after the Chernobyl accident has been the subject of extensive epidemiological research [5, 6]. In particular, only a few years after the accident a significantly increased incidence of thyroid cancer in children living in radioactively contaminated areas was reported in several studies [7, 8]. Concerning adults, a major part of epidemiological research has focused on the 600,000 Chernobyl accident clean-up workers (officially called “liquidators”) who received various doses of ionizing radiation in the moderate and low dose ranges [9, 10]. The radiation exposure to this group was mainly due to external irradiation with ^{134}Cs and ^{137}Cs. The mean individual external dose during the first year after the accident was 60mGy,169 mGy and 185 mGy for Belorus, Russian and Ukrainian clean-up workers, respectively, thereafter gradually decreasing during the following years [9]. Two main approaches may be considered in estimating the cancer risk after the Chernobyl accident. A risk projection model may be used, extrapolating results from cohorts in previous epidemiological studies, such as studies in Japanese atomic bomb survivors, to the Chernobyl accident. Using this methodology it has been suggested in a recent publication that by 2065 the accident may have caused about 40,000 cases of cancer in the whole of Europe [11]. However, such projections of results from one population to another, which differ in factors such as dose rates and genetic composition, are subject to considerable uncertainty.

Epidemiological studies on the affected population groups themselves are therefore clearly needed. A large part of epidemiological research among the Chernobyl liquidators concerns the risk of leukemia and other hematological malignancies, as leukemia has been shown to be one of the cancers most susceptible to induction by ionizing radiation. Furthermore, the latency period after radiation exposure to the development of disease has been shown to be shorter for leukemia than for most solid cancers [2].

Several early investigations, mostly cohort studies, comparing the incidence of hematologic malignancies in Chernobyl liquidators to that of the general population, have been conducted, all concluding with an increased leukemia incidence among the liquidators [12, 13]. However, the interpretation of these studies is difficult because of methodological limitations. The under-detection and under-registration of malignancies in the general population, which existed in the Soviet Union and in its former member states after its dissolution [14, 15], combined with the close medical follow-up and registration of diagnoses that were offered to the clean-up workers in the same period, might in itself have accounted for an increased incidence of leukemia in the clean-up worker group (screening bias). Furthermore, early studies were based on official radiation dose assessments, which are known to have a low degree of accuracy. In fact, it has been calculated that these estimates have an uncertainty factor in the range of 0.5-3.0 [10]. Finally, the question of confounding factors was not considered in early studies.

The aim of the present report is to review recent publications addressing the question of leukemia incidence in the Chernobyl clean-up workers and a discussion of methodological issues inherent in these studies.

COHORT STUDY

Based on the data from the Russian National Medical Dosimetry Register (RNMDR) Ivanov et al. presented in 2012 (16) a study concerning the incidence of hematological malignancies among 76.785 Russian clean-up workers from six Russian regions, who were followed for the period 1986-2007. In this study official radiation dose assessments were used without any corrections. The mean whole-body gamma radiation dose accrued over time for this cohort was 108 mGy. Age-specific incidence of leukemia in the male Russian population was used as a control. In conclusion, a significant increased radiation-related risk of leukemia among the liquidators was reported for the period 1986-1997.

Table 1. Radiation related leukemia risk in Chernobyl liquidators-
A cohort study-Ivanov et al. [16]

Cohort	75.685 Russian “liquidators”
Persons with confirmed leukemia diagnose	155
Verification of diagnose	Regionally and centrally in Russia
Control	Age specific leukemia incidence in the male Russian male Russian population
Follow-up period	1986-2007
Acertainment of diagnose in control population	No information
Documentation of radiation doses in the cohort	Official doses
Standardized Incidence Ratio (SIR) Incidence cohort/ Incidence controls	1.71 (90%CI 1.41-1.95)
Excess Relative Risk (ERR/ Gy)	1986- 1997 4. 98 p= 0,04 1998- 2007 -1.94 p= 0.20 1986- 2007 0.44 p= 0.50
Relative Risk	1986- 1997 0- 49 mGy 1 50- 149 mGy 0.71 (90% CI 0.35-1.44) 150- 500 mGy 1.90 (90% CI 1.11-3.25) 1997- 2007 0- 49 mGy 1 50- 150 mGy 0.76 (90%CI 0.47- 1.25) 150- 500 mGy 0.62 (90%CI 0.36- 1.07)
Confounders	Not considered

Excess Relative Risk (ERR) was estimated to 4,98/Gy. and a significant increase of Relative Risk (RR) was found for doses over 150 mGy in the same period. No increase in the incidence of hematologic malignancies was found for the period 1997-2007 (Table 1). The conclusions of this study are comparable to those reported in the Japanese Life Span Study, also showing an increased incidence of leukemia, occurring within the first 7-10 years after the irradiation incident, whereafter the leukemia incidence returned to baseline level. The design of this new Russian study did not differ significantly from earlier cohort studies addressing the question of leukemia incidence in the liquidators. As discussed above these studies have a number of methodological limitations, notably the risk of screening bias. For this reason considerable uncertainty also surrounds the results of this last Russian investigation.

CASE CONTROL STUDIES

In 2008 two nested case-control studies concerning a combined Belorus, Russian and Baltic cohort (Kesmeniene et al.) [17]) and a Ukraine cohort (Romanenko et al.) (18.19)) were published. In both studies the RADRUE method (Realistical Analytical Dose Reconstruction with Uncertainty Estimate) (20) was used for an individualized dose assessement. This methodology consists of a calculation of the radiation doses based on information given at a personal interview by each liquidator, or by a proxy, about the itinerary from the place of residence to the nuclear power plant, as well as the time spent during work on the accident site. This information is then coupled with available data for radiation exposure along the route to work and in the workplace itself. Furthermore, ascertainment of the diagnoses was in each case made by an international panel of pathologists. Confounding factors such as smoking, alcohol consumption and exposition to other carcinogens, and others factors, were taken into account in both studies (Table 2).

The study of Kesmeniene et al. concerns approximately 146.000 liquidators who were sent to Chernobyl in the period 1986-1987. In all, 117 confirmed cases of hematological malignancy, including non-Hodgkin lymphoma, were diagnosed in this cohort. Forty-seven cases, where a satisfactory dose assessment could not be made, were excluded from the study, which thus containing 70 cases. Controls were 287 persons from the same cohort, matched for age and country of origin. Median radiation dose for the whole cohort was 14,7 mGy and only 14% of the cohort received doses of 100mGy or more. ERR at 100mGy for all hematological malignancies together was 0.60 (90% CI – 0.02-2.35), i.e., borderline significance. Odds Ratio (OR) was elevated in all dose categories, but statistically significant only for doses over 200mGy (90% CI 1.20-11.5).

The study of Romanenko et al. concerns a cohort of 110.645 male Ukrainian clean-up workers, containing 87 cases of leukemia. Sixteen cases where a satisfactory dose assessment, or a diagnose ascertainment, could not be made were excluded. The final cohort thus consisted of 71 cases. The controls were 348 individuals from the same cohort, matched for age and region of origin in Ukraine. The case/control ratio was approximately 1:5. The mean radiation dose for cases and controls together was 76,4 mGy. Twenty-two percent of the cases received a radiation dose of 100 mGy or more. The presence of possible confounders was checked for each participant. For all cases ERR/Gy was 3.4 (95% CI 0.47-9.78). OR for the cases who received 150.0-274.9 mGy was 2.21 (95% CI 0.87-5.57) and for the cases receiving 275.0 mGy – 3220.0 mGy 2.89 (95% CI 1.12-7.46). Test for a linear trend of OR as a function of radiation exposure showed a p value of 0.03.

Thus, both studies conclude with a probable radiation-dependent increased incidence of hematological malignancies in the liquidators.

The main strengths of these two nested case-control studies are the facts that an indivdualized approach to dose assessment was made for each participant, and that the ascertainment of the diagnosis was assured by an international expert panel. The presence of confounding factors was taken into consideration in both studies.

Two main limitations may be delineated in the studies. Firstly, a considerable number of cases were excluded because available information about radiation doses or about the grounds for diagnosis were deemed insufficient. This may have created a selection bias. Also, using the RADRUE method, the dose calculations were largely dependent on information given by the liquidators themselves, or by a proxy. It may be argued that people where a hematological malignancy had been diagnosed may have had an exaggerated perception of the preceding exposition to ionizing radiation (recall bias), thus creating a systematic error in the dose estimates.

It is remarked that in both studies an increased incidence was found both for non-chronic lymphocytic leukemia (CLL) and for CLL. This is surprising, as earlier studies on the effect of occupational and environmental exposure to ionizing radiation have shown no increase of CLL incidence. CLL has therefore long been considered a non-radiogenic disease. A possible explanation of the failure to detect a radiogenic effect in CLL in earlier studies may be that CLL is in many cases a comparatively indolent disease, and therefore will often not be detected [21]. However, the assignment of CLL as non-radiogenic disease has been challenged in recent years [22]. The finding of a similar radiation effect on non-CLL and CLL in the recent studies on Chernobyl clean-up workers underlines the necessity to further investigate the association between CLL and ionizing radiation.

Table 2. Radiation related leukemia incidence in Chernobyl liquidators. Two nested case- control studies. Russian, Belorus, Baltic cohort: (Kesmeniene et al. (17)) Ukrainian cohort: (Romanenko et al. 18, 19))

	Russian, Belorus, Baltic cohort	Ukrainian cohort
Cohort	146.000 “liquidators”	110.645 “ liquidators”
Diagnoses	Leukemia, myelodysplasia, myeloproliferative disease, Non Hodgkin lymphoma	Leukemia, myelodysplasia, Non Hodkin lymphoma, multiple myeloma
Included leukemia cases	70	71
Verification of diagnose	An international panel of pathologists	An international panel of pathologists
Percentage of CLL	30.0	54.9
Time of diagnose	1990-2000	1986-2000
Documentation of Radiation doses	RADRUE method	RADRUE method
Controls	287 persons from the same cohort matched for age case/control 1:4	384 persons from the same cohort matched for age, sex and region of origine. Case/ control 1:5
Excess Relative Risk (ERR)	0.60/ mGy (90% CI- 0.02-2.35) (borderline significance)	3.44/ Gy (95% CI 0.47-9.78) $p < 0.01$
Odds Ratio (OR)	3.71 for doses $\geq$ 200 mGy (90% CI 1.20-11.5) statistically significant	*150.0 - 274.0 mGy* 2.21 (95% CI 0.87-5.57) *275.0- 3220.0 mGy* 2.89 (95% CI 1.12-7.46) test for linear trend p= 0.03
Check for confounding factors	Other radiation exposure, occupational carcinogens, organic solvents, pesticides Smoking, alcohol consumption	Educational level, urban/rural residence, exposure to chemicals, smoking, alcohol consumption

CONCLUSION

Based on these three recent studies, together with results from earlier studies, it may be concluded that an increased incidence of leukemia in Chernobyl clean-up workers, mainly occurring within the first 10 years after the accident, is probable. The results are in line with earlier studies in other cohorts, showing an oncogenic effect of ionizing radiation with doses in the moderate and low dose ranges. They are also compatible with those found in the studies on Japanese atomic bomb survivors, who were exposed to comparatively higher doserates but for a short period of time.

However, some uncertainty still remains concerning leukemia incidence the Chernobyl clean-up worker studies because of methodological limitations of the studies.

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