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Review

ON HARMONIZATION OF HEALTH RISK INDICATORS CAUSED BY IONIZING RADIATION EXPOSURE AND OTHER HARMFUL FACTORS BASED ON DALY ESTIMATES

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Radiation detriment is a basic measure which is currently applied to assess health risks caused by exposure to ionizing radiation. This concept was developed by the International Commission on Radiological Protection (ICRP) more than 30 years ago; it has both certain advantages and drawbacks that limit the scope of its possible application. A certain drawback is that this value is used exclusively to assess effects produced on health by radiation thus making it ineligible for correct comparative analysis of different risks. This review focuses on contemporary scientific papers devoted to various approaches to calculating radiation detriment. There is also an attempt to analyze whether it is possible to apply the WHO methodology for assessing burden of disease as a basis for calculating universal risk rates taking into account effects produced by exposure to harmful environmental factors on population health. A possibility to use DALY (disability-adjusted life years) estimate is considered as one of possible approaches to harmonizing health risk assessment methodologies. DALY is among estimates that are frequently used to assess population health when solving various tasks in public healthcare. The review dwells on discussing whether it is advisable and feasible to gradually change a methodology for calculating radiation detriment in order to use the effective dose as a measure of health risk more correctly.

Key words: *radiation risk, radiation detriment, DALY, public health, health risk, global burden of disease, disease severity, mortality, morbidity.*

There are three applied directions of the scientific research in health risk analysis and they all are tightly connected. The 1st one is population health analysis (including development of summary population health measures); the 2nd one is developing and calculating health risks associated with exposure to various harmful environmental factors; and the 3rd one is comparative analysis of various risks. Historically it has turned out in health risk assessment that ionizing radiation has been studied a bit apart from other various environmental factors producing negative effects on human health. Given that, issues related to harmonizing approaches to assessment of radiation risks and other health risks arise quite frequently and discussed independently [1, 2]. In addition, recently it has often been noted that it is necessary to revise the assessment methodology and measures of radiation health risks that are currently applied [3–6]. When tackling multiple issues related to public healthcare organization and population health assessment, the expert society more and more often suggest a gradual transition from mortality-based health measures to more informative summary health measures based on calculating how many years of healthy life have been lost due to disease, disability or injury, that is, number of lost healthy life years without any

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limitations on activity, functionality, and working capacities [7, 8].

This paper is a short review focusing on the latest scientific works on the aforementioned applied research directions; there is also an attempt to analyze probable ways to improve the existing methodology for radiation risk assessment and to harmonize radiation health risks with health risks caused by other harmful factors.

Radiation detriment as a health risk. The "detriment" concept[1] was first introduced in radiation protection in 1977 by the International Commission on Radiological Protection (ICRP) in its Publication 26 "to identify, and where possible, to quantify, all these deleterious effects" [9]. In general, this concept was determined in a "population" as "the mathematical expectation of the harm incurred from an exposure to radiation taking into account not only the probability of each type of deleterious effect but also the severity of the effect". "Detriment" included not only negative effects on health but also "other effects" that were not directly related to health. For example, it could be a necessity to limit consumption of specific products or use of some territories. The same document introduced a concept of "detriment to health" to estimate negative influence on human health.

At that time, data on negative health outcomes of exposure to ionizing radiation were primarily provided by observing the cohort of people who had been exposed to radiation due to atomic bombing of Hiroshima and Nagasaki in August 1945 (Life Span Study (LSS cohort)). At present, it is well-known that elevated probability of oncologic diseases in exposed people is among the most significant long-term radiological effects produced by radiation on health. A growth in this probability depends, among other factors, on a radiation dose and these outcomes can be delayed for years and even decades. In this relation as a period of observation over the LLS cohort grew longer, the character of the aforementioned dependence was constantly adjusted [11, 12].

It is important to note that the term "exposure dose" is rather specific when applied to radiation. "Dose"[2] is not measurable but rather calculated value and there is a complicated association between this value and a radiation situation in case of external exposure and introduction of radionuclides into the body in case of internal one. "Exposure dose" is used as a universal integral measure since there are multiple types of ionizing radiation ("alpha", "beta", "gamma", "neutron"). This concept allows brining all forms and types of radiation exposure to just one value, "an effective dose" which can be used to determine risks of long-term negative effects produced by exposure on health.

By 1990 when the ICRP Publication 60 was issued [13], the accumulated scientific knowledge made for formulating basic concepts applied in estimating health outcomes of exposure. Four types of such outcomes were spotted out and described: "change, damage, harm, and detriment" (more details here [14, 15]).

As a result, the ICRP developed a multidimensional measure of detriment to health and recommended it to be used for solving certain tasks related to radiological protection. This measure is a sum of lethal radiation-induced cancer cases F and a number of non-lethal cancers weighted as per lethality fraction k for specific malignant neoplasms (MNs) [14]. For a specific nosology of a MN, detriment can be given as:

$$D = F + k \cdot (1-k) \cdot \frac{F}{k} = F \cdot (2-k), \quad (1)$$

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[1] The Russian translation of the ICRP Publication 26 [9] gives both terms, "detriment" and "harm", in the same item in the text; however, the glossary made up for this Publication and the later translated ICRP Publication 60 [10] fix the distinction between them in Russian terminology.

[2] In this review, unless stated otherwise, "exposure dose" is used in the widest sense as a certain quantitative characteristics of various types of ionizing radiation. The more detailed information on various dose units can be found, for example, in this document: https://www-pub.iaea.org/MTCD/publications/PDF/IAEASafetyGlossary2007/Glossary/SafetyGlossary_2007r.pdf) and SanPiN 2.6.2523-09 "The radiation safety standards (RSS-031 99/2009)" (https://docs.cntd.ru/document/902170553) (in Russian).

where D is radiation detriment to health; F is a number of lethal radiation-induced cancers; k is lethality fraction for a MN; $\frac{F}{k}$ is the overall number of radiation-induced MNs; $(1-k)$ is a fraction of non-lethal MNs; $(1-k)\cdot\frac{F}{k}$ is the overall number of non-lethal MNs.

In the course of observation over the LLS cohort, it became obvious that assessments of radiation health risks based on data regarding detected oncologic incidence in this group were more precise than assessments based on registration of lethal cases due to cancer. Given that, without any changes in the overall concept of detriment estimation, the formula used to calculate radiation detriment was slightly changed in the ICRP Publication 103[3]:

$$R_D = R\cdot q + R\cdot(1-q)\cdot\left(q_{\min} + (1-q_{\min})\cdot q\right), \quad (2)$$

where R_D is a detriment-adjusted risk of a radiation-induced cancer[4]; R is a risk of radiation-induced cancer; q is lethality fraction for a MN; $R\cdot q$ is a risk of a lethal cancer; $R\cdot(1-q)$ is a risk of non-lethal cancers; $\left(q_{\min} + (1-q_{\min})\cdot q\right)$ is a weight attributed to non-lethal cancers when calculating detriment; $q_{\min}$ is a minimum weight for non-lethal cancers.

The weight attributed to non-lethal MNs in this formula deserves special attention and is among central elements in the methodology for assessing radiation detriment to health which is currently applied by the ICRP.

The items (A 144)–(A 145) in the ICRP Publication 103 give a clear picture of the ICRP position regarding this weighting factor and a change in it in comparison with that applied in the ICRP Publication 60 [16]:

"(A 144) *Quality of life detriment.* Cancer survivors generally experience adverse effects on their quality of life. … cancers should be weighted not only by lethality but also for pain, suffering, and any adverse effects of cancer treatment. To achieve this, a factor termed $q_{\min}$, is applied … the minimum weight for non-lethal cancer.

(A 145) The value of $q_{\min}$ was set equal to 0.1 (in most instances the result is not highly sensitive to the value chosen). …However, the $q_{\min}$ adjustment was not used for skin cancer because radiogenic skin cancer is almost exclusively of the basal cell type which is usually associated with very little pain…".

Although the ICRP was quite clear about the necessity to take into account deteriorated life quality, pain, and suffering associated with radiation-induced cancer, we can see from the structure of the weighting coefficient for non-lethal cancer that the current methodology for assessing radiation detriment neglects these factors completely. The reason is that when the ICRP recommendations were issued in 1990 there was no universal and commonly accepted methodology for assessing severity of diseases which could be considered eligible for use within the risk assessment methodology. In 2007 the ICRP Publication 103 were issued but still any revision of the implemented methodology didn't seem imminent at that moment. Besides, the ICRP didn't see development of a unified methodology for radiation risk assessment as a task to be solved. The existing methodology for detriment assessment was mostly used to develop and substantiate standardized dose values as well as to allow for differences in radiation sensitivity of specific organs, tissues, and systems in the body.

Radiation detriment as a measure was created to solve various tasks related to radiological protection (in particular, to calculate weighting factors for organs, tissues, and systems in the body taking their radiation sensitivity into account, that is, factors used to cal-

[3] As opposed to a detriment value described in the ICRP Publication 60, the authors of the Publication 103 determined the measure given below not in absolute numbers but in probabilistic values, that is in terms of risk. However, it is not important for the goals stated in this review since the transition from one values to others doesn't seem at all complicated.

[4] The term "detriment-adjusted risk" is used in the ICRP Publication 103 for this value; however, at present the authors of the methodology have abandoned it and apply the term "radiation detriment" [4].

culate a so called "effective dose"). In ICRP experts' opinion, this measure would be applied in a rather limited area. However, a value of an effective dose calculated as per this methodology turned out to be so eligible that it could spread far beyond its original application area outlined by its developers. Therefore, the ICRP managed to develop a quite successful quantitative health risk indicator and dose values that were established based on it became widely used in radiological protection. However, this indicator turned out to be ineligible for comparative assessment of different risks as it will be illustrated in detail later.

It is important to note that authoritative foreign and international scientific organizations developed mathematical models that provided an opportunity to calculate various measures of mortality and morbidity due to radiation-induced cancer [17, 18] depending on several factors such as sex and age of exposed people, exposure dose, etc. However, these rates are hardly eligible for solving tasks related to comparative risk analysis. It is to a great extent due to medical radiological outcomes of exposure being delayed and it means that the radiation factor can actually be compared only with those factors which produce comparably delayed effects. And there is still no solution to the task how to comparatively analyze diseases which have different severity and are caused by exposure to different risk factors. All these aforementioned reasons call for developing such risk measures that are eligible for comparative analysis and take into account severity of diseases and different distribution of risk realization over time.

Summary measure of population health and assessment of disease severity. Summary measures of population health give a clear picture of complex epidemiological data; they can be used to create effective development strategies for public healthcare systems with respect to prevention of the most socially significant diseases [19]. These measures are primarily applied to:

– assess population health "in different social groups in dynamics";

– provide the best possible insight into what diseases, injuries and risk factors make the greatest contribution to deteriorating health of a specific population including identification of the most significant health issues and their dynamic, that is, whether they get better or worse over time (this is probably the most widely spread application of summary health measures);

– assess whether there are sufficient amounts of precise and qualitative data on population health [19].

Summary measures of population health have been developed for more than 50 years[5] [20]. Over many years population health has been assessed using only mortality-based indicators. In other words, population health was determined by how and why people died or reasons for mortality and its rates [19, 21].

Life expectancy, mortality due to all reasons, infant (children) mortality and mortality due a specific disease were compared between regions, countries, and on the international level [22].

Currently, a methodology applied to calculate most summary measures of population health[6] is based on analyzing age-sex-specific mortality rates due to various reasons and epidemiology of nonfatal diseases. For example, the profile of the "Public healthcare" national project contains certain targets fixed for the period 2019–2024 and some of them directly concern population health assessment (the first 4 targets) but all these targets are mortality-based ones [23]. Targets stated by the RF Public Healthcare Ministry within the National Security Strategy of the Russian Federation

[5] Hereinafter Summary Measures of Population Health (SMPH) mean such integral values characterizing expected health as health index or unified mortality and morbidity index.

[6] An important reservation here is most postulates stated in this section concern exclusively summary measures of population health and not analysis of medical and demographic data as a whole. A great number of variable partial indicators can be used in the latter case to give a picture of specific aspects in population health.

have some additions such as “life expectancy at birth” and “average life expectancy of patients with a chronic pathology after it has been diagnosed”[7]. Meanwhile, such measures as well as any measures based on data on morbidity, birth rate or disability among population, do not provide us with comprehensive but still effectively brief information which is eligible for assessing population health as a whole or for analyzing whether public healthcare systems are being developed efficiently enough[8]. In particular, some important aspects are neglected including severity of chronic diseases, long-term or permanent disability, and injuries [21].

Obviously, it is quite convenient to use mortality-based measures when solving multiple tasks related to health risk analysis [24, 25]. Primarily, a death case due to exposure to a harmful factor is clear enough as a measure of risk. Incidence is no less clear measure of risk though it is not so informative with relation to population detriment [26]. Since these measures are truly clear and simple to be estimated, they have become widely used in population health assessment [27]. Thus, for example, the state report issued by Rospotrebnadzor and entitled “On sanitary-epidemiological welfare of the population in the Russian Federation in 2020”[9] mentions several groups of primary population health measures. They can be influenced by various sanitary-hygienic factors; when it comes down to physical and/or chemical risk factors, the report covers the following measures:

1) Overall morbidity among population;
2) Overall mortality among population;
3) Sex-specific incidence with temporary disability;
4) Injuries and poisonings;
5) Congenital malformations in children;
6) Infant mortality, birth rate, natural population decrease;
7) Prevalence of:
– respiratory diseases;
– digestive diseases;
– circulatory diseases;
– malignant neoplasms;
– congenital malformations in children.

Such population health measures based on mortality and morbidity are simple, graphic and widely used; their use resulted in health risks rates due to exposure to harmful environmental factors also being frequently determined based on mortality and morbidity.

Meanwhile, these measures have at least two serious drawbacks which are significant for describing health risks [28] [10]:

1) when assessing health risks caused by weak exposure to an environmental factor or exposure to a factor that has not been studied profoundly[11], the assessment results given as “expected number of death cases” or “expected number of diseases” can create a false idea of actual outcomes of such an exposure and they often do just that;

2) these measures produce rather scarce data on detriment to population health when effects are long-term and delayed over time since they don’t provide an opportunity to directly estimate both economic outcomes of adverse exposure on the state level (for example, those related to temporary or permanent disability) and average individual risks (for

[7] O Strategii natsional'noi bezopasnosti Rossiiskoi Federatsii: Ukaz Prezidenta Rossiiskoi Federatsii ot 02.07.2021 № 400 [On the National Security Strategy of the Russian Federation: The Order by the RF President issued on July 02, 2021 No. 400]. *KonsultantPlus*. Available at: http://www.consultant.ru/document/cons_doc_LAW_389271/ (December 14, 2021) (in Russian).

[8] To be fair, we should note that targeting should be considered exclusively with respect to its relation to formulating specific goals achievement of which should be analyzed using these established targets.

[9] O sostoyanii sanitarno-epidemiologicheskogo blagopoluchiya naseleniya v Rossiiskoi Federatsii v 2020 godu: Gosudarstvennyi doklad [On sanitary-epidemiological welfare of the population in the Russian Federation in 2020: The State Report]. Moscow, The Federal Service For Surveillance over Consumer Rights Protection and Human Wellbeing, 2021, 256 p. (in Russian).

[10] R 2.1.10.1920-04. Rukovodstvo po otsenke riska dlya zdorov'ya naseleniya pri vozdeystvii khimicheskikh veshchestv, zagryaznyayushchikh okruzhayushchuyu sredu [Guide R 2.1.10.1920-04. Human Health Risk Assessment from Environmental Chemicals]. Moscow, The Federal Center of the State Sanitary and Epidemiological Surveillance of the RF Public Healthcare Ministry, 2004, 143 p. (in Russian).

[11] It concerns exposure to small radiation doses, low concentrations of chemicals and other adverse exposures they create a lot of uncertainties in risk assessment.

example, when average life expectancy decreases in a given risk group) [29].

Indeed, occupational injuries tend to have almost instant outcomes (death, temporary or permanent disability) whereas occupational exposures (that is, when workers employed at radiation-hazardous objects face exposures which are fractioned over time) can have outcomes that become obvious after many years. Besides, occupational injuries are personalized whereas risks related to exposure to harmful factors are often estimated as probabilistic for one person or as a frequency for a group of people (attributable risks).

Health as a concept, apart from meaning "absence of a disease", also means there are no disorders or functional limitations due to previous diseases and injuries. The WHO determines health as "a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity"[12] [30]. Summary health measures have been developed to take this factor into account in population health analysis together with developing systems for collecting medical and demographic data. The measures were being developed the most actively in 90ties last century. It was exactly at that time when age-sex-specific mortality and morbidity rates grouped as per their causes were added with new developing measures that were more informative and allowed for functional limitations and decreased working abilities as well as factors that reduced "quality of life" due to disease or disability[13]. This activity was to a great extent due to the WHO creating and developing a new project entitled "Global Burden of Disease" (hereinafter GBD) [31].

One of its targets was to quantify population burden due to premature deaths and disability for the most common diseases and groups of diseases as well as to quantify years of life lost due to the aforementioned reasons and years of life with complete or partial disability weighted as per a degree of their severity [31].

According to GBD terminology and ICF classification (International Classification of Functioning, Disability and Health) by the World Health Organization (WHO) [32]), the term "disability" is widely used in analyzing disease severity (Burden of Diseases) to determine deviations from good or ideal health. These deviations include limitations in the following spheres: mobility, self-care, participation in usual activities, pain and discomfort, anxiety and depression, and cognitive impairment [33].

Such an approach to health assessment suing a standard description of health was, for example, applied in the WHO GBD 2000 project [34].

A list of summary health measures developed by various organizations is quite wide and can be conditionally divided into two main groups:

1) Health Expectancies;

2) Health Gaps.

The first group includes the following measures [35]:

1) HALE or Health-Adjusted Life Expectancy;

2) DFLE or Disability Free Life Expectancy;

3) DALE or Disability-Adjusted Life Expectancy;

4) ALE or Active Life Expectancy; etc.

The second group includes such measures as:

1) DALY or Disability-Adjusted Life Years;

2) QALY or Quality-Adjusted Life Years.

When measures from the first group are calculated, the process, as a rule, involves taking into account not only mortality but also disability induced by various reasons. Differences in calculations of these measures occur due to use of various weights and approaches to allowing for significance of diseases and

[12] Constitution of the WHO. Available at: https://www.who.int/governance/eb/who_constitution_en.pdf (December 15, 2021).

[13] Taking into account poorer quality of life due to disease or acquired disability usually involves using specific values with the common name HRQL (Health-Related Quality of Life) [19].

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other reasons for health deterioration [36, 37]. Besides, some measures, such as DFLE, for example, don't allow for any differences in severity of health disorders since they all have the same zero weight when the measure is calculated. That is, DFLE takes into account only "perfect health". And if calculating a measure involves taking into account various severity of "not perfect health", different weights are recommended to be used for the several "categories of health disorders".

The second group that includes so called HALY measures[14] describes influences exerted by reasons that cause health deterioration on a reduction in healthy life, that is, changes in population health due to a specific health disorder in comparison with a situation when this disorder is absent.

To calculate HALY measures associated with a specific disease, we should complete three basic tasks:

1. To describe a health state associated with this disease;

2. To develop a numeric measure or a weight for this health state;

3. To combine numeric measures of each health state with estimated life expectancies [19].

If we consider using summary measures of health as a probable measure of risk associated with impacts exerted on health by various environmental factors, then, obviously, measures from the second group are more eligible for the purpose since they can reflect exactly changes in health. In other words, they allow quantifying a difference between health of a given population group without any exposure to a harmful factor and health influenced by this exposure, that is, spotting out a component associated directly with this exposure to this harmful factor.

At present it is QALY and DALY that are the most widely used measures combining life expectancy estimates and health estimates. But still there are certain differences in how DALY and QALY are used in practice [35].

QALY measures were developed in early 1970ties as "a health index" that combined life expectancy and quality. First, they were applied in tuberculosis screening. At present QALY are primarily used to make economic estimates by multiple regulating authorities that consider cost-effectiveness analysis to be an integral part of decision-making. QALY measures make it possible to compare interventions into health that can make life longer but have severe side effects (for example, permanent disability due to radiotherapy or chemotherapy in cancer treatment) with interventions that raise quality of life without making it longer (for example, palliative aid or pain relief) [19].

DALY is a summary measure of population health that combines mortality and nonfatal health outcomes. Initially this measure was developed to quantify severity of diseases within the GBD project aiming to measure a relative loss of healthy life associated with different reasons for disease or disability [30]. Procedures for calculating DALY are based on the assumption that time is the most eligible indicator of disease severity and it includes a period of time with disability and a period of time lost due to dying early [19].

The basic principle in calculating DALY is that each disease or any other reason for reduced working abilities is weighted taking its severity into account (starting from 0 which means "good health" and up to 1 which means death). On the population level, this weight is multiplied by exposure duration as well as by a number of people exposed to a specific disease or any other reason for losing their full working abilities. Therefore, DALY is calculated as a sum of years lost due to dying early and lost years of healthy life resulted from not being completely healthy due to harmful exposure. "A major advantage this measure has is an opportunity to summarize outcomes caused by various exposures (for example, environmental ones) as well as to combine quantitative and qualitative characteristics of life"[15].

[14] Health-Adjusted Life Years is the common term to describe a group of measures including DALY, QALY etc.

[15] Bychkova S.G. Sotsial'naya statistika: uchebnik dlya akademicheskogo bakalavriata [Social statistics: the manual for academic bachelor students]. Moscow, Izd-vo Yurait, 2019, 864 p. (in Russian).

QALY and DALY measures can be and are actually applied when estimating returns on investments into public healthcare, though only QALY was initially designed for this purpose [35]. The most significant difference between DALY and QALY measures is that QALY is more eligible for assessing medical intervention with the focus on consequences this intervention might have on quality of life whereas DALY measure allows quantifying negative effects produced by a disease itself on average individual or population levels bearing in mind "disease severity" or population burden ("disease burden"[16]). Therefore, it is DALY measure which is much better as a basis for calculating losses associated with exposures to variable harmful factors.

Most generally, formula applied to calculate DALY can be given as follows:

$$DALY = YLL + YLD, \quad (3)$$

where YLL is years of life lost due to premature death, that is, a number of years a person failed to live up to an average life expectancy due to dying early caused by a disease; YLD is a number of years lived with disability caused by disease or any other reason.

In its turn,

$$YLL = M \times LE, \quad (4)$$

where M is a number of deaths due to condition; LE is standard life expectancy at age of death.

YLD is calculated as per the following formula which includes a weighting factor showing a decrease in quality of life due to disease:

$$YLD = DW \times I \times DD, \quad (5)$$

where I is a number of nonfatal incident cases; DD is average duration of disability due to specific disease until remission (or death); DW is weighting factor of specific condition that reflects decreasing quality of life due to this condition.

The methodology for calculating DALY has been constantly developed [22, 38]. At present DALY calculation allows a possibility to assign different weights to years lived with health disorders at different age. When experts use weights for different ages (in some procedures for calculating DALY), they usually prefer young adults to infants and elderly people since this population cohort is considered to be a "more productive" part of the society and makes the greatest contribution into economic development. However, this approach is not accepted in some countries. Weighting age-related factors are probably the most controversial social parameters applied in DALY calculations.

Age- and disability-related weights are not the only social values applied in calculating DALY measures. The GBD project implementation outlined some other issues (in addition to those discussed above: standard number of years lost due to premature death and disability weights) influencing how and why DALY are calculated:

1) How long "should" people live?

2) Is a year of life saved today more valuable for the society than a year of healthy life preserved in the future, say, 20 years from now?

3) Should years of healthy life be estimated differently at different age? For example, the GBD project gives more value to a year of a young adult than those of an elderly person or an infant.

4) Are all people equally important?

5) Do all people of specific age lose the same number of healthy years due to death even if their life expectancy is different in different social groups? [39].

However, not all experts agreed with this approach regarding both differences and

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[16] In the Russian text of the paper, this term, "burden of disease", is translated word by word here since it is used in this way in official Russian translations of the WHO publications. Still, it seems a rather poor translation and the authors try to avoid this exact word-by-word variant in the Russian text replacing it with synonymic word combinations which seem more appropriate to them.

weights. When this approach is applied, it makes DALY measure more an economic indicator showing productivity of people who have specific medical condition.

Critics state there are three major ethical problems related to using QALY and DALY measures:

– They don't fully take into account condition of people with poor social status or poor health. Elderly people and people who already have certain healthy disorders make contributions into lower HALY measures since there is only limited potential for improving their health;

– Similarly, these measures discriminate people with limited possibility to be treated or people who are less likely to recover (For example, people with already diagnosed healthy disorders or diseases);

– Both measures don't take into account qualitative differences in outcomes (for example, saving a life against a simple recovery) due to the applied procedure for summarizing mortality and morbidity rates. Health measures and disease measures are combined for all people and for the whole range of health states, starting from its perfect one and down to death. It means that differences between activities aimed at saving a life and those aimed at improving health are neglected. Aggregating as a specific issue also raises a question whether we should estimate insignificant benefits for many people in the same way as significant benefits for just some of them [19].

At present new estimation procedures are being developed which are much better in allowing for social peculiarities and not only can solve the aforementioned ethical issues but also provide a clearer idea of population health.

Therefore, assessment of "disease severity" is the most interesting in terms of scientific research. It can be used as a key parameter for including diseases, injuries, and disabilities into summary health measures which do not result in death but reduce functional abilities, make life shorter and its quality poorer. It is interesting, both theoretically and practically, to search for balance in two directions: 1) balance between health self-assessment and quality of life due to disease, injury or disability and objective health state and functionality, 2) balance between socioeconomic (different social groups have different "value" for a state and its economy[17]) and humanistic (all lives matter equally regardless of sex, age, race, nationality, health or any other social properties) estimates of "significance" assigned to different population groups.

Development of measures for assessing radiation detriment. The TG-102 team presented a report during the 2nd session "Risks and effects" at the International online-conference "The Future of Radiological Protection" which was organized in October 2021 by the ICRP. The report focused on developing a methodology for calculating radiation detriment and specifically outlined how the existing methodology could be improved in future [40]. There were five major spheres for this improvement outlined in the report:

1) update of baseline data and parameters for detriment calculation;

2) revision of "dose – effect" models and the procedure for risk assessment transfer between populations;

3) handling of variation with sex and age in detriment calculation;

4) increasing transparency and comprehensibility of parameters;

5) consideration of non-cancer effect.

The authors outlined three major components for the first sphere: 1) use of actual statistical data on cancer incidence rates and mortality rates; 2) use of data on other populations other than selected Asian and Euro-American

[17] Whether it is ethical to take this factor into account when calculating summary measures of population health is a question to be discussed separately [20]. As a rule, authorities in countries with high income per capita believe all lives are equally valuable whereas authorities in countries where public healthcare budgets are limited have to keep in mind that their possibilities to develop public healthcare are rather limited when determining priority spheres for funding.

ones; 3) adjustment of weighting factors reflecting severity of nonfatal[18] diseases.

The second and fifth items in the list to a greater extent concern summarizing results produced by epidemiological studies whereas the remaining items are more applied and methodological ones. There have been frequent attempts to calculate detriment using more up-to-date medical and demographic data on specific populations (Russian, in particular) [41, 42]; also there have been often changes in some parameters in detriment calculation, such as lethality fraction for cancers etc. [5, 6]. Attempts to take into account risk dependence on sex and age under exposure are also quite frequent, especially when it comes down to assessing risks caused by medical radiation [43–45].

Much less attention has been paid so far to the most fundamental question, that is, the value of detriment, its actual meaning and practical necessity [46]. Meanwhile, as it has been mentioned above, this value needs revising and rethinking; this task is vital due to all the progress which has been achieved recently in population health assessment together with obsolescence of data applied to calculate detriment, medical-demographic and other data as well as due to existing practices in using detriment and its derivatives.

Thus, for example, Shimada K. and Kai M. used DALY in their work as a possible measure for an excess cancer risk following radiation exposure [46]. Based on the results produced by their estimates, they concluded that the IRCP overestimated a contribution made by leukemia risk and underestimated those made by breast cancer and thyroid gland cancer. They also noted that the value of detriment had a drawback and it was that it couldn't be adequately interpreted or applied. Contrary to opinion expressed by many experts, detriment is not a risk for the whole population since it is calculated for a hypothetic population including people of different sexes, different ages, and belonging to different ethnical communities. They also noted that multi-dimensional detriment used in radiation protection was determined as a radiation risk measure, in particular, when it comes down to comparing fatal and nonfatal cancers. They also pointed out that the existing concept of detriment could be used only for comparing effects produced by different exposure doses.

This change in paradigm of assessing detriment to health in the applied sphere should undoubtedly be provided with convicting scientific and practical substantiation. Structural similarities between radiation detriment and DALY measure allow examining several variants for applying the methodology for estimating global burden of diseases in assessing radiation detriment and developing relevant measures:

1) The simplest approach is to directly replace weights assigned to nonfatal cancers in detriment calculation with respective DW measures applied in DALY calculation. This approach would require some changes at the last stage in calculating weighting factors for various organs and tissues since detriment values[19] for nonfatal cancers of specific organs and tissues are already calculated bearing in mind a number of lost years of healthy life whereas fatal cancers are not weighted allowing for this measure.

2) Radiation detriment values are de facto used as a predictive risk rate to solve multiple practical tasks related to providing radiation safety although the ICRP directly pointed out that it wasn't correct to use detriment value in such a way. Given that, it would seem advisable to use actual medical and demographic data on specific populations when calculating numbers of radiation-induced cancers and linear coefficients of radiation detriment for the most significant age-sex-specific population groups. This would make risk assessments based on using them more practically significant even in spite of all well-known uncertainties occurring in such assessments.

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[18] Nonfatal diseases in this case are diseases caused by exposure to ionizing radiation and resulting in reducing one's life and making its quality poorer but not in death. This concept is not about a specific nosology in general but only about a share of disease cases that occur among exposed people due to exposure but are not the primary reason for their deaths.

[19] Or detriment-adjusted risk as given in the glossary of the ICRP Publication 103 [14].

3) Finally, calculating DALY linear coefficients per a radiation dose unit and simultaneous use of both these measures in risk assessment could make for gradual implementation of up-to-date radiation detriment measures without violating succession in traditions and the necessity to retrain a great number of experts.

Our analysis of data available in literature assuredly indicates that studies with their focus on developing the risk assessment methodology are vital and also determines the most promising trends in future research.

Conclusions. Based on analysis of all literature sources stated in the references to this article, we can conclude the following:

1. A gradual change in the paradigm of assessing negative influence on population health by various environmental factors, that is, health risk analysis, is an applied aspect in the development of the health assessment. Summary health measures based on population mortality caused by exposure to harmful factors are replaced with measures based on reduction in number of years of healthy life due to the same exposure; this approach should be adopted in decision-making processes in multiple spheres.

2. Implementation of DALY measures into the health risk assessment methodology can provide several advantages in comparison with other existing approaches:

– DALY-based risk assessments allow more correct comparison of negative effects produced by exposure to a harmful factor on population health in case risks realization is distributed differently over time;

– DALY-based risk assessments make comparative risk analysis between different populations simpler since they take into account population differences much more exactly than when risks are comparatively analyzed based on standardization of sex-age-specific medical and demographic parameters;

– procedures for estimating disease severity are being constantly developed and this allows estimating the actual situation with national public healthcare systems and providing their most precise picture in health risk analysis. In particular, it is true for progress in diagnostics and treatment of specific diseases;

– population risk assessments based on lost years of healthy life don't create a false perception of actual death cases in a situation when there is no epidemiological proof of negative effects produced on numerous population groups by exposure to very small doses of a harmful factor, that is, in a situation when negative effects are considered to likely occur only due to extrapolation from higher doses (exposures).

3. A rapid change in the risk assessment paradigm hardly seems feasible and is rather unadvisable. It seems more realistic to gradually change the system of risk measures by applying the methodology for assessing disease severity developed within the GBD project to quantify health risks associated with exposure to various environmental factors. Simultaneously it is possible to use DALY values per a unit of a harmful factor as a measure for assessing harmful effects on health.

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References

1. Demin V.F., Zakharchenko I.E. Risk vozdeistviya ioniziruyushchego izlucheniya i drugikh vrednykh faktorov na zdorov'e cheloveka: metody otsenki i prakticheskoe primenenie [The risk of exposure to ionizing radiation and other harmful factors for human health: assessment methods and practical application]. *Radiatsionnaya biologiya. Radioekologiya*, 2012, vol. 52, no. 1, pp. 77–89 (in Russian).

2. Korenkov I.P., Demin V.F., Soloviev V.Yu. Problems of the establishment of dose – effect relationship for risk assessment under exposure to ionizing radiation and harmful chemical substances. *Gigiena i sanitariya*, 2019, vol. 98, no. 7, pp. 687–700. DOI: 10.18821/0016-9900-2019-98-7-697-700 (in Russian).

3. Cléro E., Bisson M., Nathalie V., Blanchardon E., Thybaud E., Billarand Y. Cancer risk from chronic exposures to chemicals and radiation: a comparison of the toxicological reference value with the radiation detriment. *Radiat. Environ. Biophys.*, 2020, vol. 60, no. 4, pp. 531–547. DOI: 10.1007/s00411-021-00938-2

4. Cléro E., Vaillant L., Hamada N., Zhang W., Preston D., Laurier D., Ban N. History of radiation detriment and its calculation methodology used in ICRP Publication 103. *J. Radiol. Prot.*, 2019, vol. 39, no. 3, pp. R19–R35. DOI: 10.1088/1361-6498/ab294a

5. Zhang W., Laurier D., Cléro E., Hamada N., Preston D., Vaillant L., Ban N. Sensitivity analysis of parameters and methodological choices used in calculation of radiation detriment for solid cancer. *Int. J. Radiat. Biol.*, 2021, vol. 96, no. 5, pp. 596–605. DOI: 10.1080/09553002.2020.1708499

6. Breckow J., Emami S., Amalhaf S., Beshgard A., Buermeyer J., Spruck K. Impact of updating the non-radiation parameters in the ICRP 103 detriment model. *Radiat. Environ. Biophys.*, 2021., vol. 57, pp. 89–98. DOI: 10.1007/s00411-018-0731-z

7. Kobyakova O.S., Deyev I.A., Boikov V.A., Milkevich M.N., Kulikov E.S., Naumov A.O., Golubeva A.A., Shibalkov I.P. Possible application of DALY to health assessment of population in Russia. *Sotsial'nye aspekty zdorov'ya naseleniya*, 2015, no. 2. Available at: http://vestnik.mednet.ru/content/view/660/30/ (12.12.2021) (in Russian).

8. Starodubov V.I., Marczak L.B , Varavikova E., Bikbov B., Ermakov S.P., Gall J., Glenn S.D., Griswold M. [et al.]. The burden of disease in Russia from 1980 to 2016: a systematic analysis for the Global Burden of Disease Study 2016. *The Lancet*, 2018. vol. 392, no. 10153, pp. 1138–1146. DOI: 10.1016/S0140-6736(18)31485-5

9. Publikatsiya 26 MKRZ. Radiatsionnaya zashchita [ICRP Publication 26. Recommendations of the ICRP]. *Trudy MKRZ*. Moscow, Atomizdat, 1978, 88 p. (in Russian).

10. Publikatsiya 60 MKRZ. Radiatsionnaya bezopasnost'. Rekomendatsii Mezhdunarodnoi komissii po radiologicheskoi zashchite 1990 goda. Chast' 2 [ICRP Publication 60. Radiation protection. 1990 Recommendations of the International Commission on Radiological Protection. Part 2]. In: I.B. Keirim-Markus ed. *Trudy MKRZ*. Moscow, Energoatomizdat, 1994, 208 p. (in Russian).

11. Preston D.L., Shimizu Y., Pierce D.A., Suyama A., Mabuchi K. Studies of mortality of atomic bomb survivors. Report 13: solid cancer and noncancer disease mortality: 1950–1997. *Radiat. Res.,* 2012, vol. 178, no. 2, pp. AV146–AV172. DOI: 10.1667/rrav12.1

12. Ozasa K., Shimizu Y., Suyama A., Kasagi F., Soda M., Grant E.J., Sakata R., Sugiyama H., Kodama K. Studies of the mortality of atomic bomb survivors, Report 14, 1950–2003: an overview of cancer and noncancer diseases. *Radiat. Res.*, 2012, vol. 177, no. 3, pp. 229–243. DOI: 10.1667/rr2629.1

13. ICRP Publication 60. Radiation protection. 1990 Recommendations of the International Commission on Radiological Protection. Part 2. In: H. Smith ed. *Annals of the ICRP*, vol. 21, no. 1–3. Oxford, Pergamon Press, 1991, 211 p.

14. ICRP Publication 103. The 2007 Recommendations of the International Commission on Radiological Protection. In: J. Valentin ed. *Annals of the ICRP*, 2007, vol. 37, no. 2–4, 339 p.

15. Repin L.V. On the use of detriment parameters for the quantitative evaluation of radiation exposure consequences. *Radiatsionnaya gigiena*, 2011, vol. 4, no. 1, pp. 35–37 (in Russian).

16. Publikatsiya 103 MKRZ. Rekomendatsii 2007 goda Mezhdunarodnoi komissii po radiatsionnoi zashchite [ICRP Publication 103. The 2007 Recommendations of the International Commission on Radiological Protection]. In: M.F. Kiselev, N.K. Shandala eds. *Trudy MKRZ.* Moscow, OOO PKF "Alana", 2009, 344 p. (in Russian).

17. EPA 402-R-11-001. EPA Radiogenic Cancer Risk Models and Projections for the U.S. Population. *U.S. Environmental Protection Agency*, Washington, D.C., 2011, 175 p.

18. UNSCEAR 2006 Report. Effects of ionizing radiation. Vol. 2. New York, United Nations Publ., 2009, 338 p.

19. Lajoie J. Understanding the Measurement of Global Burden of Disease. *National Collaborating Centre for Infectious Diseases*, 2015, 22 p. Available at: https://nccid.ca/wp-content/uploads/sites/2/2015/03/Global_Burden_Disease_Influenza_ENG.pdf (20.12.2021).

20. Murray C.J.L., Salomon J.A., Mathers C. A critical examination of summary measures of population health. *Bull. World Health Organ.*, 2000, vol. 78, no. 8, pp. 981–994.

21. Gold M.R., Stevenson D., Fryback D.G. HALYs and QALYs and DALYs, Oh My: similarities and differences in summary measures of population health. *Annu. Rev. Public Health*, 2002, vol. 23, no. 1, pp. 115–134. DOI: 10.1146/annurev.publhealth.23.100901.140513

22. Sassi F. Calculating QALYs, comparing QALY and DALY calculations. *Health Policy Plan.*, 2006, vol. 21, no. 5, pp. 402–408. DOI: 10.1093/heapol/czl018

23. Pasport natsional'nogo proekta «Zdravookhranenie» [The profile of the "Healthcare" national project]. Available at: http://static.government.ru/media/files/gWYJ4OsAhPOweWaJk1prKDEpregEcduI.pdf (12.12.2021) (in Russian).

24. Harris E.C., Palmer K.T., Cox V., Darnton A., Osman J., Coggon D. Trends in mortality from occupational hazards among men in England and Wales during 1979–2010. *Occup. Environ. Med.*, 2016, vol. 73, no. 6, pp. 385–393. DOI: 10.1136/oemed-2015-103336

25. Chen Y.-H., Glymour M., Riley A., Balmes J., Duchowny K., Harrison R., Matthay E., Bibbins-Domingo K. Excess mortality associated with the COVID-19 pandemic among Californians 18–65 years of age, by occupational sector and occupation: March through November 2020. *PLoS One*, 2021, vol. 16, no. 6, pp. e0252454. DOI: 10.1371/journal.pone.0252454

26. Popova A.Yu. Working conditions and occupational morbidity in the Russian Federation. *Meditsina truda i ekologiya cheloveka*, 2015, no. 3, pp. 7–13 (in Russian).

27. Onishchenko G.G., Popova A.Yu., Zaitseva N.V., May I.V., Shur P.Z. Health risk analysis in the tasks of improving sanitary and epidemiological surveillance in the Russian Federation. *Health Risk Analysis*, 2014, no. 2, pp. 4–13. DOI: 10.21668/health.risk/2014.2.01.eng

28. EPA 100-B-00-002. Risk Characterization: Science Policy Council Handbook. *U.S. Environmental Protection Agency*. Washington, DC, 2000, 189 p.

29. Thacker S.B., Stroup D.F., Carande-Kulis V., Marks J.S., Roy K., Gerberding J.L. Measuring the public's health. *Public Health Rep.*, 2006, vol. 121, no. 1, pp. 14–22. DOI: 10.1177/003335490612100107

30. Salomon J.A. Disability-Adjusted Life Years. *Encyclopedia of Health Economics*. Elsevier, 2014, pp. 200–203. DOI: 10.1016/b978-0-12-375678-7.00511-3

31. Mathers C.D. History of global burden of disease assessment at the World Health Organization. *Arch. Public Health*, 2020, vol. 78, pp. 77. DOI: 10.1186/s13690-020-00458-3

32. Ustün T.B., Chatterj S., Bickenbach J., Kostanjsek N., Schneider M. The International Classification of Functioning, Disability and Health: a new tool for understanding disability and health. *Disabil. Rehabil.*, 2003, vol. 25, no. 11-12, pp. 565–571. DOI: 10.1080/0963828031000137063

33. The Global Burden of Disease concept. *WHO*. Available at: https://www.who.int/quantifying_ehimpacts/publications/en/9241546204chap3.pdf (12.12.2021).

34. Murray C.J.L., Lopez A.D., Mathers C.D., Stein C. The Global Burden of Disease 2000 project: aims, methods and data sources. *WHO*, 2001, 57 p. Available at: https://www.who.int/healthinfo/paper36.pdf (12.12.2021).

35. Handbook of disease burdens and quality of life measures. In: V.R. Preedy, R.R. Watson eds. New York, Springer, 2010, 4446 p. DOI: 10.1007/978-0-387-78665-0

36. Ruan X., Li Y., Jin X., Deng P., Xu J., Li N., Li X., Liu Y. Health-adjusted life expectancy (HALE) in Chongqing, China, 2017: An artificial intelligence and big data method estimating the burden of disease at city level. *Lancet Reg. Health West. Pac.*, 2021, vol. 9, pp. 100110. DOI: 10.1016/j.lanwpc.2021.100110

37. Lee J.Y., Ock M., Kim S.H., Go D.S., Kim H.J., Jo M.W. Health-Adjusted Life Expectancy (HALE) in Korea: 2005–2011. *J. Korean Med. Sci.*, 2016, vol. 31, suppl. 2, pp. 139–145. DOI: 10.3346/jkms.2016.31.S2.S139

38. Chen A., Jacobsen K.H., Deshmukh A.A., Cantor S.B. The evolution of the disability-adjusted life year (DALY). *Socio-Econ. Plan. Sci.*, 2015, vol. 49, pp. 10–15. DOI: 10.1016/j.seps.2014.12.002

39. The global burden of disease: a comprehensive assessment of mortality and disability from diseases, injuries, and risk factors in 1990 and projected to 2020: summary. In: C.J.L. Murray, A.D. Lopez eds. *WHO*. Boston, Harvard School of Public Health Publ., 1996, 41 p.

40. Ban N., Clero E., Vaillant L., Zhang W., Hamada N., Preston D., Laurier D. Possible Improvements of Methodology for Calculating Radiation Detriment in the Future. *ICRP*. Available at: https://icrp.org/admin/Live%20Sessions/SLIDES_2-2_NobuhikoBan.pdf (12.12.2021).

41. Gorski A.I., Chekin S.Yu., Maksioutov M.A., Menyajlo A.N., Korelo A.M., Tumanov K.A., Zelenskaya N.S., Lashkova O.E., Ivanov V.K. Transfer of ICRP models of radiation risk to the population of the Russian Federation. *Radiatsiya i risk*, 2019, vol. 28, no. 4, pp. 5–15. DOI: 10.21870/0131-3878-2019-28-4-5-15 (in Russian).

42. Ivanov V.K., Chekin S.Yu., Kashcheev V.V., Maksyutov M.A., Korelo A.M., Menyailo A.N. Issledovanie vliyaniya neopredelennosti fonovykh pokazatelei zabolevaemosti na prognoz radiatsionnykh riskov po modelyam MKRZ dlya rossiiskikh populyatsii pri odnokratnom obluchenii [Effect produced by uncertainty of baseline incidence rates on estimating radiation risks with ICRP models for Russian populations following single exposure to radiation]. *Radiatsiya i risk*, 2013, vol. 22, no. 3, pp. 40–56 (in Russian).

43. Andersson M., Eckerman K., Pawel D., Almén A., Mattsson S. Improved radiation risk models applied to different patient groups in Sweden. *Radiation Hygiene*, 2019, vol. 12, no. 2, pp. 44–54. DOI: 10.21514/1998-426X-2019-12-2-44-54

44. Golikov V.Yu., Vodovatov A.V., Chipiga L.A., Shatsky I.G. Evaluation of radiation risk for patients undergoing medical examinations in the Russian Federation]. *Radiatsionnaya gigiena*, 2021, vol. 14, no. 3, pp. 56–68. DOI: 10.21514/1998-426X-2021-14-3-56-68 (in Russian).

45. Ivanov V.K., Tsyb A.F., Mettler F.A., Menyaylo A.N., Kashcheev V.V. Health risks of medical radiation exposure. *Radiatsiya i risk*, 2011, vol. 20, no. 2, pp. 17–28 (in Russian).

46. Shimada K., Kai M. Calculating disability-adjusted life years (DALY) as a measure of excess cancer risk following radiation exposure. *J. Radiol. Prot.*, 2015, vol. 35, no. 4, pp. 763–775. DOI: 10.1088/0952-4746/35/4/763

Repin L.V., Akhmatdinov R.R., Biblin A.M., Repin V.S. On harmonization of health risk indicators caused by ionizing radiation exposure and other harmful factors based on DALY estimates. Health Risk Analysis, 2022, no. 1, pp. 162–175. DOI: 10.21668/health.risk/2022.1.18.eng

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