METHODOLOGICAL ASPECTS OF THE HYGIENIC REGULATION OF IONIZING RADIATION

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Technologies based on ionizing radiation (IR) are used in many areas of human activity, ranging from nuclear energy and national defense to medical diagnosis and therapy. Consequently, the hygienic assessment of the effects of IR is a scientifically and practically important interdisciplinary problem. This study aimed to analyze the challenges encountered and the approaches used to assess the radiation dose–effect relationship, thereby substantiating the need to harmonize radiation safety standards (RSS) at the current stage and highlighting the central role of evidence-based and preventive medicine in this field. We reviewed, researched, and analyzed IAEA's "Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards" and Russian SanPiN (sanitary norms and regulations) documentation, dose-related recommendations issued by the Russian Ministry of Health between 2020 and 2025, radiation therapy software solutions, and training manuals and clinical practice guidelines. The effort revealed a discrepancy between national, departmental, and international standards, dose tiers, and units of measurement. In some professions, such as piloting and spaceflight, occupational exposure to ionizing radiation exceeds the natural terrestrial background level by tens or even hundreds of times. The radiation-therapy doses specified in the Russian Ministry of Health's clinical recommendations differ by as much as tenfold across anatomical sites. There is a shortage of educational software designed to teach radiation therapy treatment planning. The authors translated three textbooks published by the IAEA and WHO into Russian and made these freely available. The following measures were identified as feasible and advisable: organizing interdepartmental cooperation on the development and approval of new RSS, taking into account current Russian and international practices; verifying radiotherapy dose recommendations in clinical guidelines; aligning dose categories for specific professions and harmonizing methods for assessing occupational radiation risks; and supplementing university curricula with radiotherapy-planning software, as well as WHO and IAEA textbooks and guidelines.

Keywords: ionizing radiation, radiation safety standards, occupational health, doses

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МЕТОДИЧЕСКИЕ АСПЕКТЫ ГИГИЕНИЧЕСКОГО НОРМИРОВАНИЯ ИОНИЗИРУЮЩИХ ИЗЛУЧЕНИЙ

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Технологии на основе ионизирующих излучений (ИИ) проникли во многие сферы человеческой деятельности — от атомной энергетики и оборонных комплексов до медицинской диагностики и терапии, что делает проблему гигиенической оценки воздействия ИИ междисциплинарной и сохраняющей высокую научно-практическую значимость. Целью работы было проанализировать проблемы и подходы к верифицированной оценке влияния «доза–эффект» физического фактора ИИ для обоснования целесообразности унификации на современном этапе норм радиационной безопасности (НРБ) и императива доказательной и профилактической медицины. Проанализированы публикации НРБ МАГАТЭ и СанПиН, дозы по клиническим рекомендациям Минздрава России 2020–2025 гг., ряд компьютерных систем дозиметрического планирования, учебные пособия и пособия для специалистов. Имеет место несоответствие национальных, ведомственных, международных норм, доз, единиц измерений. Люди некоторых профессий (летчики, космонавты) подвергаются воздействию ИИ, превышающему естественный фон на земле в десятки и сотни раз. В клинических рекомендациях Минздрава России дозы для лучевой терапии разной локализации различаются в десятки раз. Зафиксирован недостаток учебных компьютерных систем по планированию лучевой терапии. Авторами переведены на русский язык для открытого использования три учебных пособия МАГАТЭ, ВОЗ. Признано целесообразным организовать межведомственное взаимодействие при разработке и утверждении новых НРБ с учетом современного российского и международного опыта; верифицировать дозы лучевой терапии в клинических рекомендациях; унифицировать дозы для отдельных профессий и методики оценки профессиональных радиационных рисков; внедрить в образовательный процесс вузов компьютерные программы планирования лучевой терапии, учебные пособия и руководства ВОЗ, МАГАТЭ.

Ключевые слова: ионизирующие излучения, нормы радиационной безопасности, гигиена труда, дозы

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Ionizing radiation (IR), discovered during the nineteenth and twentieth centuries, has been extensively studied and applied throughout the twentieth and twenty-first centuries. Dosimetry systems have been developed for a wide range of settings, including industrial, environmental, and space environments, while dose–effect relationships have been established through evidence-based medical research. IR-based technologies are widely used in key areas of human activity, including nuclear energy, national defense, medical diagnostics and therapy, basic scientific research, and radiation therapy involving cyclotrons and synchrotrons. Therefore, the hygienic assessment of the effects of IR constitutes an interdisciplinary problem of substantial scientific and practical importance. According to the WHO (2023), more than 4.2 billion diagnostic radiology examinations, 40 million nuclear medicine procedures, and 8.5 million radiotherapy treatments are performed worldwide each year. "Physicist expert in the control of ionizing and non-ionizing radiation sources" and "medical physicist" are occupations included in the list approved by an order of the Russian Ministry of Health issued in 2023 [1]. The requirements include higher education and a specialist or master's degree in medical physics. However, effective radiation control requires harmonized and approved standards, including maximum permissible levels (MPLs) for ionizing radiation and maximum permissible doses (MPDs). To ensure effective and safe radiotherapy, single boost doses (SBDs) and total boost doses (TBDs) should also be clearly defined. At the international level, efforts to harmonize standards across departments have led to the transfer of responsibility from several specialized organizations within the UN system to the IAEA, which coordinates, synthesizes, and publishes work on this topic in cooperation with the WHO [2]. In Russia, radiation safety standards (RSS) are traditionally approved by Rospotrebnadzor.

This study aimed to analyze the challenges encountered and the approaches used to assess the radiation dose–effect relationship, thereby substantiating the need to harmonize radiation safety standards (RSS) at the current stage and highlighting the central role of evidence-based and preventive medicine in this field.

Materials and methods

We compared international and Russian regulatory frameworks, including the IAEA Safety Standards and SanPiN, regulatory enforcement practices, clinical dose recommendations issued by the Russian Ministry of Health between 2020 and 2025, several radiotherapy software solutions, training manuals, and practical guides.

The evolution of IR units of measurement and modern unification in the SI system

In 1928, roentgen was adopted as the first international unit for measuring IR. Later, within the period from the 1940s to the 1970s, several units have been defined and introduced, including curie, rutherford, erg, coulomb/kg, J/kg, rad, rem as roentgen equivalent, rem as roentgen equivalent-man, etc., with some used with time time units. The large number of parameters and the growing body of knowledge about dose–effect relationships threatened to make the field of dosimetry confusing [3]. In 2018, the General Conference on Weights and Measures (CGPM) approved revisions to the International System of Units (SI), as described in the ninth edition of the SI Brochure [4]. Among other provisions, the activity of a radionuclide is expressed in becquerels (Bq), the absorbed dose and kerma in grays (Gy), and the equivalent dose in sieverts (Sv). The ninth edition of the SI Brochure contains a section entitled "Units for quantities that describe biological and physiological effects." It states that, in medical diagnostics and therapy, units that cannot yet be expressed in SI units are also used to quantify biological activity. The mechanisms of action of some biological agents have not yet been sufficiently elucidated to permit their activity to be expressed in terms of physicochemical parameters. Because of the importance of these agents to health and safety, the WHO has assumed responsibility for defining the International Units (IU) of biological activity. Neither the SI Brochure nor the WHO documents refer to "international units" for radiopharmaceuticals used in diagnosis or brachytherapy. This may be important both for planning effective brachytherapy treatments and in the context of the launch of Europe's largest radiopharmaceutical production complex in Obninsk. The activities of the International Commission on Radiation Units and Measurements (ICRU) should also be mentioned here, including its work on photon-beam radiation therapy [5].

Unification of safety standards at the level of specialized UN agencies

Research on the health effects of ionizing radiation has been ongoing for more than 120 years, with contributions from several international organizations, including the International Commission on Radiological Protection (ICRP) [6], the International Organization for Medical Physics (IOMP), and the International Agency for Research on Cancer (IARC). At the international level, responsibility for the development of radiation-safety standards was transferred in 2012 from the WHO to the International Atomic Energy Agency (IAEA). On behalf of the sponsoring organizations — the WHO, the International Labour Organization (ILO), the Pan American Health Organization (PAHO), the Food and Agriculture Organization of the United Nations (FAO), and the United Nations Environment Programme (UNEP) — the IAEA published the "Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards" (IAEA IBSS) [7]. The contribution of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) should also be noted. Its 2022 report to the United Nations General Assembly "Sources, Effects and Risks of Ionizing Radiation" provided a comprehensive global assessment of the frequency and doses of medical exposure to ionizing radiation, trends across medical categories, and occupational exposure [8].

Radiation safety standards (RSS) in Russia, expediency of comparative analysis, updating and interagency cooperation

Rospotrebnazor, as the heir to the USSR state sanitary supervision system, traditionally approves RSS in Russia. This tradition makes sense given the historically established levels of social hygiene and health care; radiation hygiene, occupational hygiene, hygiene of children and adolescents, preventive medicine, including the prevention and control of cancer (the second leading cause of death), the identification of risks to public health, and the prevention of the negative effects of physical factors. However, the RSS were approved and incorporated into the Sanitary Rules and Regulations 15 years ago [9, 10]. Since then, the units of measurement and irradiation standards have changed, and a substantial body of data has been accumulated in this field, necessitating an update to Russian legislation. In Russia, production control, the approval of standards, radiation-dose monitoring, and federal oversight of compliance are currently distributed across multiple departments and are carried out by Rospotrebnadzor, Roszdravnadzor, the Ministry of Health, Rostechnadzor, the Federal Medical Biological Agency, the Russian Academy of Sciences, Rosatom, Rostech, the Ministry of Defense, Roscosmos, and other bodies [11–14]. Taking into account international experience and Russian specifics, prospects for development in medical physics, nuclear, aerospace and other sectors of the economy, it is advisable to organize interdepartmental cooperation in the development and approval of new RSS. An obstacle on the path is the problem of cancellation of licensing: there is no agency that oversees the process of licensing the maintenance of ionizing radiation generating sources used in medicine, radiological medical devices; this function can be transferred to Roszdravnadzor. As the first step, it is feasible to analyze the qualifications, instrumentation, and staffing for a specialized federal supervision and production control.

Some aspects enabling an in-depth comparative analysis that should be considered in the updated RSS

The new SanPiN 2.6.4115-25 introduced in 2025 [15] confirm the relevance and validity of the basic SanPiN 2.6.1.2523-09 (NRB-99/2009) [9] and SP 2.6.1.2612-10 (OSPORB-99/2010) [10]. It should be noted that SanPiN 2.6.4115-25 uses the curie for expressing high levels of activity. Although the curie has been approved for use in Russia since 2009 [16], it is a non-SI unit and is generally regarded as obsolete for scientific and technical use. It has therefore been superseded by the becquerel, the corresponding SI unit of activity. The National Institute of Standards and Technology (NIST) strongly discourages the continued use of the curie, as well as the roentgen, rad, and rem [17]. In its recommendations, the International Organization of Legal Metrology (OIML) classifies the curie, rad, and roentgen as units of measurement that may be used temporarily until the date established by national regulations but should not be introduced where they are not already in use [18]. This provision should be taken into account in future reviews of Russian legislation. The annual dose limits and associated fatal risks specified in SanPiN NRB-99/2009 are consistent with those in ICRP Publication 103 (2007) and the IAEA Basic Safety Standards, except for the neutron radiation-weighting factor, which is represented as a continuous function. Meanwhile, the tissue-weighting factors and their corresponding risk coefficients are based on ICRP Publication 60 (1991); however, there are no data or references related to the later ICRP Publication 103 (2007) [6].

Radiological tests and maintenance of ionizing radiation sources: Russian standards and control practice

The importance of dosimetric monitoring during X-ray examinations in Russia has been demonstrated by radiation-hygiene specialists [19, 20]. The Decree of the Government of the Russian Federation [21] and the order of the Ministry of Health of the Russian Federation [1], as legislative documents, cover "non-medical use of IR" and the respective licensing practice. There has been published an analysis of radiation accidents in radiation and radionuclide diagnostics and therapy that compares Russian and international approaches to terminology and classification [22].

Prospects for the development of radiation therapy in Russia: the need for medical and technical standardization

According to analytical reviews, Russia's fleet of high-tech radiotherapy equipment meets the standards of developing countries [23]. In 2020, the Government of the Russian Federation issued a resolution supporting the development of synchrotron- and neutron-based treatment infrastructure [24]. The resolution also set the goal of bringing proton therapy in Russia up to the global standard by 2027 and designated the Kurchatov Institute as the lead organization for implementing the program [25]. At the same time, healthcare planning in Russia should factor in the growing problem of uneven availability of high-tech medical assistance in the country, and design remedial measures for this problem. To date, these barriers remain difficult to overcome, as specialized treatment modalities — including proton therapy, neutron therapy, neutron-capture therapy, Gamma Knife radiosurgery, and carbon-ion therapy — are available only at centers located in certain regions. Consequently, patients may have to travel thousands of kilometers to obtain treatment. Neutron-capture therapy is being researched in Novosibirsk at the Budker Institute of Nuclear Physics [26] and also at the National Research Nuclear University MEPhI, jointly with the Blokhin Russian Cancer Research Center and the Burnasyan Federal Medical Biophysical Center. Regions of Russia receive modern radiotherapy technology unevenly. For example, the Southern Federal District (SFD) and the North Caucasus Federal District (NCFD), which together are home to 27 million people, have no proton- or neutron-therapy units or other high-tech radiotherapy facilities. A feasible initial-stage effort would involve a country-wide analysis of the current situation and the development of measures to facilitate the deployment of high-tech equipment and the recruitment and training of relevant personnel, including medical engineers — such as specialists in biotechnical systems and technologies — healthcare managers, and other professionals. The resulting action plan should draw upon international experience, including the IAEA's approach to planning radiotherapy services [27]. To improve and harmonize the practices of medical engineers and technicians who service radiotherapy equipment in clinics, the authors of this study and their colleagues translated the WHO–IAEA international technical specifications for radiotherapy equipment used in cancer treatment into Russian and made the translation publicly available [28].

Radiation doses in radiation therapy: from the evolution of guidelines to evidence-based medicine and dose unification in Russia

In radiation therapy, the current Sanitary Rules and Regulations (SanPiN) follow the ALARA principle ("as low as reasonably achievable"), which was formally introduced by the ICRP in 1977. That is, without directly setting dose limits for patients, radiotherapy specialists expand the limits of permissible exposure to the extent they deem necessary. In Russian SanPiNs, there are no concrete numbers supporting the ALARA principle followed, which creates legal uncertainty. For example, clause 5.4.1 of SanPiN 2.6.1.2523-09 (NRB-99/2009) states: "...dose limits for patients are not established; instead, the principles of justification of medical procedures and optimization of patient protection are applied." Under paragraph 4.4 of the Sanitary Regulations SP 2.6.1.2612-10 (OSPORB-99/2010), "therapeutic radiological procedures should be justified taking

Table 1. Analysis of the number, range, lower and upper limits of radiation doses (Gy) for radiation therapy of various types of neoplasms from 90 issued of clinical recommendations by the Ministry of Health of Russia (2020–2025)

Treatment protocol	Number of fractions	Single boost dose, Gy	Total boost dose, Gy
Protocols from the Ministry of Health of Russia, 2020–2025	1.0–50.0	0.5–40.0	2.0–180.0

into account the requirements: the risk of rejection of radiation therapy obviously exceeds the risk of radiation exposure during its implementation"; there are no references to specific generally accepted calculations of "risks." According to clause 4.7 of SP 2.6.1.2612-10 (OSPORB-99/2010), "optimization of radiation protection of patients should provide for achieving a beneficial medical effect of radiological procedures, or a therapeutic result, at the lowest possible radiation levels." The international initiative "Quantitative Analysis of Normal Tissue Effects in the Clinic" (QUANTEC) should also be noted. It involves compiling databases of dose–effect relationships for various organs and tissues based on long-term follow-up data [29, 30]. The situation has changed due to the accumulation of experimental results and the determination of doses in the clinical recommendations of the Ministry of Health of the Russian Federation (Ministry of Health of the Russian Federation), approved on the basis of a decree by the Government of the Russian Federation [31]. Preventive medicine, guided by the principle of "do no harm," and evidence-based medicine, which ensures the effectiveness of treatment, are increasingly gaining prominence. This is an important factor: single and total boost doses prescribed by the Ministry of Health of the Russian Federation in the respective guidelines are exactly what a plan of a radiotherapy course begins with. We analyzed the number, range, and limits (Gy) of doses in the context of photon therapy recommended for various neoplasms in 90 clinical guidelines approved by the Ministry of Health of the Russian Federation between 2020 and 2025. The guidelines were retrieved from the "Clinical Recommendations" (clin-rec) section of the Ministry's official website (Table 1).

The analysis revealed that the dose values in 90 issues of clinical recommendations by the Ministry of Health of the Russian Federation can vary tenfold: single boost dose (SBD) — from 0.5 to 40.0 Gy, total boost dose (TBD) — from 7.0 to 180.0 Gy. It should be noted a large number of reputable specialists participated in the development of each recommendation, and the most doses therein are supported by references to publications in foreign sources.

On the one hand, the variation in the recommended SBD and TBD values across different nosologies may be considered expected and biophysically (i.e., in relation to hard and soft tissues) and radiobiologically (i.e., in relation to radiosensitivity) justified. However, similar variation is also observed within individual nosologies, including differences in the recommended stage-dependent doses, radiation modalities, and equipment. Therefore, these discrepancies warrant further investigation, validation, dosimetric analysis, and explanation.

In the course of this study, we developed a tabular matrix presenting clinical recommendations of the Russian Ministry of Health; this matrix accumulates data for the primary analysis of radiation doses. Table 2 presents examples from specific protocols. Its purpose is to provide a picture demonstrating the scale of the problem.

The tenfold differences in radiation doses recommended by the Russian Ministry of Health for various oncogenic target organs can be compared with the differences in tissue weighting factors used to calculate effective dose: under SP 2.6.1.2612-10 and ICRP Publication 60 (1991), these factors varied 20-fold, from 0.01 for bone surfaces to 0.20 for the gonads; under ICRP Publication 103 (2007), they varied 12-fold, from 0.01 to 0.12. This may also indicate the need for further work in the field of evidence-based medicine, calculations, and reasoned explanations.

Standards and guidelines for specialists, aspects of hyperinformational multidepartmental work, expediency of unification, comparison with international experience

Given its long history of nuclear technology development, extensive nuclear industry, and numerous economic sectors that use ionizing radiation, Russia has developed numerous guidelines and recommendations on radiation safety. The official regulatory framework includes SanPiNs published on the Rospotrebnadzor website in the section "List of Regulatory Legal Acts Containing Mandatory Requirements for the Use of Ionizing Radiation Sources." It also includes guidelines (MU) and recommendations (MP) issued or approved by Rospotrebnadzor that address radionuclide diagnostics using radiopharmaceuticals (MU 2.6.1.1892-04), radiation therapy (MU 2.6.1.2135-06), brachytherapy (MU 2.6.1.2712-10), and the management of the consequences of radiation accidents (MP 2.6.1.0360-24), among other areas. In addition, the framework comprises state standards (GOST) approved by Rosstandart, including standards for personal protective equipment against ionizing radiation for medical personnel (GOST R 58168–2018), methods for monitoring radiation therapy (GOST R 57517–2017), radiometric instruments (GOST R 57518–2017), and radiometric monitoring (GOST R 72075–2025). Finally, it includes 103 current regulatory documents (NP) containing federal norms and rules in the field of atomic energy use, published on the official Rostechnadzor website. The system of radiation safety regulations approved and controlled by Rostechnadzor is developed under Article 6 of Federal Law No. 170-FZ [32]. From the viewpoint of law, it is important for public health. In particular, there is an ongoing discussion about the approval of standards for the maximum permissible emissions of radioactive substances into the atmospheric air and the establishment of the boundaries of the sanitary protection zone (SPZ) around the site of a NPP [33]. The latter is significant for expert appraisals of the documentation of new NPPs, including Southern NPP and other nuclear power plants planned for construction up to 2042, as approved

Table 2. Tabular matrix of radiation doses from protocols described in the clinical recommendations (two examples)

Nosological unit	SBD, Gy	TBD, Gy
Prostate cancer*	1.8–19.0	8.0–160.0
Follicular lymphoma**	1.8–2.0	4.0–30.0

Note: * — Prostate cancer. ICD-10: C61. Clinical recommendations. Moscow: Ministry of Health of the Russian Federation, 2021; ** — Follicular lymphoma. ICD-10: C82, C85.9. Clinical recommendations. Moscow: Ministry of Health of the Russian Federation, 2024.

Table 3. Radiation exposure limits for specialists of the ISS partner agencies and occupational exposure standards in SanPiN NRB-99/2009 and the IAEA IBSS

Space agencies, Rospotrebnadzor, the IAEA — subjects of limit setting	Career limit/occupational norms	Gender/age relationship
Roscosmos * Canadian Space Agency * European Space Agency *	1000 mSv	None
Japan Aerospace Exploration Agency *	3 % REID on average	Lower limit: 500 mSv for women aged 27 to 30 years. Upper limit: 1000 mSv for men over 46 years of age
NASA (current) *	3 % REID at confidence level of 95 %	Lower limit: ~180 mSv for women 30 years old. Upper limit: ~700 mSv for men 60 years old.
NASA (proposed update) *	600 mSv	None
Rospotrebnazor, occupational radiation norms, SanPiN NRB-99/2009	Annual dose limits 100 mSv in 5 years/ but not more than 50 mSv per year	None
The IAEA, occupational radiation norms, the IAEA-2015 IBSS	Annual dose limits 100 mSv in 5 years/ but not more than 50 mSv per year	None

Note: * — data from [47].

by the Government of the Russian Federation [34]. The IAEA has developed numerous publications for specialists, including "Pocket Guide for Medical Physicists Supporting Response to a Nuclear or Radiological Emergency" [35]; "Radiation Protection and Safety in Medical Uses of Ionizing Radiation," developed in cooperation with the WHO and ILO [36]; "Selecting Megavoltage Treatment Technologies in External Beam Radiotherapy," which addresses radiation safety considerations [37]; IAEA Nuclear Safety and Security Glossary [38]; the IAEA's "Determination of Absorbed Dose in Remote Radiation Therapy: International Practical Recommendations on Dosimetry" [39]; and the report "Accuracy Requirements and Uncertainty Factors in Radiation Therapy" [40]. There are lists of literature in Russian for medical physicists working in the field of radiation therapy of neoplasms [41].

Standardization of radiation safety in aerospace medicine

Studies that investigated the effect of IR on the health of pilots have shown that at altitudes from 9000 to 12000 m, the intensity of ionizing radiation can exceed the natural radiation background by 31-41 times [42]. The risk of IR influence on pilots' health has been studied [43]. The effective doses received by aircraft crew members from cosmic radiation were compared with the dose limits recommended by international organizations [44]. However, there are no approved radiation safety limits in aviation medicine. Another study collated the radiation safety experience accumulated in Russia over the sixty years of manned space flights with Russian legislation and international recommendations [45]. The respective standards were analyzed retrospectively, as were estimates of the total radiation risk and the potential reduction in cosmonauts' life expectancy during long-term orbital and interplanetary flights [46]. Against the backdrop of the International Space Station (ISS) orbiting Earth, national space agencies currently adopt different approaches to dose limits, relating them to sex and age and defining the dose threshold in terms of the risk of radiation-induced death (REID) [47]. Table 3 presents a comparison of dose limits.

The relevance of the strategies of national space agencies and their joint projects in the field of manned flights and research is steadily increasing. Federal Law [48] approved cooperation between the Russian Federation and China in the International Scientific Lunar Station project. NASA's Moon to Mars Objectives [49] sets out an objectives-based framework for the agency's human deep-space exploration efforts. The framework includes the Artemis program and the gradual development of lunar infrastructure to support subsequent crewed missions to Mars. The risks of space exploration are borne by a small group of people — cosmonauts, astronauts, taikonauts, and viomanauts — while society as a whole benefits from their work. This imbalance makes space agencies responsible for maximizing the protection of their specialists (spacecraft and station hulls, spacesuits, exposure time), minimizing operational disruptions during flight, throughout their careers, and after leaving the agencies. Efforts are being made to predict the risks associated with lunar and Martian missions, taking into account mission duration (days), absorbed dose (Gy), effective dose (mSv), and risk of death (%) [47]. Russian researchers and engineers are developing radiation safety measures that would apply in a nuclear-powered spacecraft [50].

Higher education and university textbooks on medical physics, radiation hygiene, and dosimetry

The IAEA has identified a need for medical physicists in radionuclide therapy and diagnostic imaging [51]. There is a noteworthy paper that analyzes why medical dosimetry is a profession only in the USA and what it means for medical physicists all over the world [52]. The relevance of providing dosimetric support in Russia for planning and evaluating the effectiveness of treatment as a fundamental methodological basis for modern radionuclide therapy has been confirmed [53]. In education and science communication, it is advisable to adopt a rational approach based on the principles of evidence-based medicine and information hygiene. This can help prevent radiophobia and provide concise, reliable information to people seeking knowledge in today's hyperinformational society [54]. In Russia, textbooks on radiation hygiene, dosimetry, and radiation medical physics for universities have been written and compiled by specialists from several universities and research institutes [55–61]. Due to their diversity and quantity, it is important to harmonize their contents while taking into account international experience. There are also international textbooks by the IAEA. They are prepared by leading specialists from dozens of countries. These textbooks cover a wide range of topics, including radiation physics, dosimetry and instrumentation, image quality and perception, visualization methods, specialized applications, advances in digital technology, radiation biology, radiation protection, and safety standards. They have also been approved by several international professional organizations, and can be useful for those preparing for certification as medical physicists or radiologists. Despite the fact that Russia is a member of the IAEA, a number of voluminous textbooks have not been translated into Russian. The authors, together with colleagues, translated extensive (total volume 1,494 pages) textbooks published by the IAEA on the physics of nuclear medicine and diagnostic radiology for teachers and students into Russian and made them publicly available [62, 63].

Dosimetric planning educational software

In accordance with Government of the Russian Federation directives on digital transformation in higher education [64] and healthcare [65], it is particularly important to assess the availability, development, and university-based training related to computer systems for dosimetric radiotherapy planning, as well as their implementation in clinical practice. This assessment should cover treatment-plan verification, dose calculation, evaluation of treatment efficacy and safety, and other relevant functions, while taking into account the clinical recommendations by the Russian Ministry of Health, international experience, medical and technical support, and international clinical recommendations [39, 40]. We found that in 2026, Russian radiotherapists use 12 clinical dosimetric planning platforms, none of which is educational. Abroad, there are 33 such solutions, and 5 of them are used for training purposes. The list of Russian systems includes AMPHOTA, Gammaplan RT, ScanPlan, Plan B, Plan N, Plan D, Rplan, Plan X DLT, Plan P, Plan NE, Plan I, MMS. Foreign solutions are 3DVH, Accuray, Contour+, Corvus, Delta4DVH Anatomy, Eclipse, ERGO++, FULLACCESS, GPT-RadPlan, HDR+, MultiPlug, iPlan RT, MIM Symphony, MONACO, Multiplan, MIM Maestro, Panther TPS, Plan W, BrainlabElements, PlanIQ, Prism, RapidPlan, SagiPlan, Spot, SunSCAN 3D, Theraplan Plus, TOPAS, Tracer, VariSeed, Vitesse, XiO-CE 3D, Pinnacle, Focal. Training systems — FoCa, MuriPlan, OpenTPS, PortPy, Vert. Fourteen solutions are dosimetric planning complexes for teletherapy and brachytherapy, 29 — only for teletherapy, and 7 for brachytherapy.

CONCLUSION

The increasing prevalence of ionizing radiation (IR) resulting from technological advances, the expansion of human activities, and its growing use in medicine requires increased attention to its effects on public health, healthcare organization, radiation regulation, and the higher education and training of qualified specialists. It is important to organize interdepartmental cooperation in the development and approval of new radiation safety standards, taking into account the historically established Russian specifics and modern international experience.

For highly specialized on-site assessments, it is advisable to:

– evaluate the qualifications of specialists, the staffing levels of medical physicists, the availability of experts qualified to measure physical factors for specialized federal supervision and production control, and the availability of appropriate measuring instruments;

– harmonize occupational radiation risk assessments and dose standards for individual professions;

– introduce the WHO and IAEA international textbooks into the curricula of universities, and to develop educational computer systems for radiation therapy dosimetric planning.

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