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## ANALYSIS OF RADIATION THERAPY EQUIPMENT STATUS IN UKRAINE

The **subject** matter of the article is review and analysis of existing radiation treatment technologies, availability and efficiency of use of modern radiotherapy equipment in regions Ukraine according to European radiotherapy development trends. The **goal** of the work is to analyze the current status of radiotherapy equipment in Ukraine and to find the ways for extension of its use. The following **tasks** were solved in the article: the analysis of distribution of radiotherapy machines in Ukraine, estimation of current number of radiotherapy machines per million people for all regions and needs of radiotherapy centers of Ukraine in high precision conformal treatment machines. The following **methods** used – documentary data analysis, comparison and summarizing. The following **results** were obtained – estimated that according to requirements of IAEA that necessary number of megavoltage treatment machines in Ukraine should be near 200. Use of 90 machines covers only 45% needs of Ukrainian population in radiation treatment. According to DIRAC data 61 of 65 Co-60 machines in Ukraine are used during more than 20 years, Co-60 sources in 23 these machines now have Dose rate less than 0.4 Gy/min and must be replaced urgently. **Conclusions:** The main actual aspects of technical status of equipment for External-beam radiation therapy in Ukraine were discussed. Existing radiotherapy facilities were analyzed from the point of view of real needs and possibilities of Ukrainian radiation oncology. As a conclusion, the results of this analysis demonstrate a significant heterogeneity in the access to modern radiotherapy equipment in different regions of Ukraine. The qualitative analyses of used radiotherapy equipment demonstrate its significant technical backwardness. The results of this analysis may be used as technical recommendations for improvement of radiotherapy facilities in Ukraine.

**Keywords:** external beam radiation therapy; megavoltage machines; linac.

### Introduction

Radiation therapy is one of the most complex and technologically equipped branches of medicine. The high energy radiation sources are successfully used for destroying or slowing of tumor growth. Approximately half of all patients with cancer worldwide should receive radiotherapy. However, more than 2 million people are unable to access it because of a lack of Radiotherapy megavoltage machines (MVM) [1]. So the necessity of use of MVM is only rises year by year. According to cancer incidence worldwide trends the World Health Organization (WHO) assumed that it may increase by a further 1.2 million new cases per year by 2030, pushing the annual incidence to more than 23 million [1-3]. Such morbidity causes huge pressing on economics and increases social burdens in any country. So improving the effectiveness of therapeutic technologies allow significantly limit the negative effects of cancer incidence. That's why monitoring of state of radiation therapy technological capacities and in-time upgrading of high-energy radiation equipment become very significant challenges for providing effective oncology medical care. They even may be used as index for evaluation the level of economic, social and innovation positions of any country of the world [4]. The direct correspondence exists between availability and efficiency of use of modern radiotherapy equipment and level of scientific and technical development and socioeconomic conditions [5].

### Analysis of last achievements and publications

The situation with the providing of radiation therapy technologies in 206 countries is constantly monitored by the IAEA [6, 7]. The results of annual registering of IAEA are shown in database Directory of Radiotherapy Centres (DIRAC), which includes data not only on teletherapy machines, but also on sources and devices used in brachytherapy, and on equipment for dosimetry, patient

dose calculation and quality assurance etc. DIRAC is a powerful tool that can be used for different types of analyses: to assess existing infrastructure in radiotherapy, plan new radiation oncology centres and extract performance and quality indicators related to radiotherapy services.

A megavoltage teletherapy machine MVM is defined as either a clinical linear accelerator of electrons (photon beam energy ranges from 6 to 18 MeV) or radionuclide Cobalt-60 machine (mean  $\gamma$ -radiation energy is 1.25 MeV). Clinical linear accelerators or LINACs are radiation treatment devices that accelerate electrons using electromagnetic fields to a required energy, transform the energy of electrons to high-energy bremsstrahlung to deliver radiotherapy. Radionuclide treatment machines have internal gamma-ray emitting source for use in radiotherapy. Both machines are used for external beam radiation treatment or teletherapy, where Source-to-Surface Distance may be 0.8 m or 1 m.

According to [7] there are 14 217 teletherapy MVMs in use worldwide now. In some high developed country particle accelerators are also used for external radiation treatment. They accelerate hadrons (heavy particles such as protons and carbon ions) using electromagnetic fields to high energy beams (60 - 250 MeV for protons and 350-400 MeV for carbon ions), useful for medical purposes. Particle accelerators produce the best therapeutic effects but this equipment is huge and very expensive as for general use. Thus now only 116 proton-ion accelerators are used, mostly in USA (56 acc.) and Japan (21 acc.).

Radiation Therapy Equipment market worldwide is projected to grow by US\$3.5 Billion, driven by a compounded growth of 6.2%. External Beam Radiation Therapy displays the potential to grow at over 6.3% [8]. The leading MVMs manufacturers are Varian Medical Systems (USA) and Elekta (Sweden).

According to DIRAC data [7] availability of MVM estimated as Number of Radiotherapy Machines Per Million People, which is significantly varies for groups of

countries with different income (table 1).

**Table 1.** Data on radiation therapy facilities contained in the DIRAC database [7] according to countries income

IncomeGroup	Countries	Countries with RT	RT centers	Equipment per million population.	RT machines	Million population	Linac	Radio-nuclide teletherapy	Circular accelerator	Particle accelerator
<b>Grand Total</b>	<b>206</b>	<b>151</b>	<b>7495</b>	<b>1,921</b>	<b>14449</b>	<b>7521</b>	<b>12302</b>	<b>2018</b>	<b>13</b>	<b>116</b>
High income (H)	71	60	4478	7,740	9111	1177	8696	297	11	107
Upper middle income (UM)	56	45	2270	1,509	4028	2670	2903	1116	1	8
Lower middle income (LM)	46	33	726	0,428	1273	2973	684	588	0	1
Low income (L)	32	12	20	0,049	34	700	16	17	1	0

The Western European average number of MV machines per million inhabitants is 6.875 MVM, for Eastern Europe respectively 2.775 MVM [7]. The survey [9] showed a significant heterogeneity in the access to modern radiotherapy equipment. High income countries especially in Northern-Western Europe are well-served with radiotherapy resources, other countries are facing important shortages of both equipment in general and especially machines capable of delivering high precision conformal treatments Intensity-Modulated Radiation Therapy (IMRT) and Image-Guided Radiation Therapy (IGRT) [10]. Information about equipment for IMRT and IGRT was available for 26 countries; 69% MVMs were equipped for IMRT and 49% for IGRT. There was 96 dedicated stereotactic radiotherapy (SRT) or radiosurgery (SRS) units in 13 Western European countries [9].

For countries with Low income (0.049 MVM/mln) and Lower middle income (0.428 MVM/mln) radiation treatment often is unavailable for their inhabitants. So for these countries it's very important to choose optimal conception for step by step growth of their radiation therapy facilities by taking to account evaluation of their real economic conditions [11, 12]. For large-territory countries geographic accessibility to radiotherapy also should be estimated [13].

According to IAEA recommendations the number of radiotherapy megavoltage machines (MVMs) required to meet the global cancer demand was calculated by estimating that 500 courses would be performed on each MVM per year in LMIC. Given the likely higher complexity of treatments in HIC, 400 courses per MVM per year were estimated for these countries [1].

### Highlight of the earlier unresolved parts of the general problem. Aim of the study

Despite having general information presented by DIRAC [7] the deep analysis of problem of availability and estimation technological level of Radiotherapy MVM in Ukraine is insufficient [5, 14]. The impACT mission's experts, nominated by the IAEA and WHO to audit Ukraine in 2019, pointed that access to quality diagnostic and therapeutic radiation medicine services in the public sector in Ukraine needs to be improved [15]. The aim of this study is to analyze the current status of radiotherapy equipment in Ukraine and to find the ways for extension of its use. Such analysis can help to equalize access to radiation treatment among regions of Ukraine.

## Materials and methods

The current study includes a detailed analysis of radiotherapy equipment based on Data collection of DIRAC, fact-finding the data of country profile, 5-year retrospective analysis of status of radiotherapy equipment in Ukraine. The following methods are used: documentary data analysis, comparison and summarizing.

## Study results and their discussion

### Availability of Radiotherapy equipment.

Ukraine is classified by DIRAC IAEA as Low Middle Income country with level of availability 2.14 EBRT machines per 1 million of population (fig.1). Is this enough? According to GLOBOCAN 2018 data number of new cancer cases in Ukraine reached 169 817 and among them 60% (near 100 000 cases) need radiotherapy [3]. As IAEA recommended for LMIC [1] the capacity of one MVM should be near 500 treated patients per year. Thus desired number of MVMs in Ukraine should be near 200. In fact 90 MVMs are used in Ukraine now (fig. 2). It means that radiotherapy may be available only for 45% of Ukrainian cancer patients.

The capacity of MVMs in Ukraine is significantly different: between 200 and 1000 treated patients per one linac and between 400 and 2000 per one Co-60 machine. It is evident that some MVMs worked with considerable overload, however, thanks to the efforts of our excellent specialists, 42 312 Ukrainian patients received radiation treatment during 2019. These results confirmed that approximately 45% of the demand in treatment was satisfied, but technical reserves of MVMs have been exhausted. Unfortunately, near 55% of Ukrainian patients did not receive radiation treatments as required by international protocols of cancer treatment.

Next challenge for Ukraine is loss of control of 17% of its radiotherapy equipment in part of territory which is occupied since 2014 due to Russian aggression. As shown on fig.1 real availability of MVMs in Ukraine is worse than DIRAC represented. The lack of lost equipment (17 Co-60 machines and 2 linacs) is compensated by the overload of 71 available Ukrainian MVMs.

The territorial distribution of MVMs is shown on fig. 1. Number of Radiotherapy Machines per Million People in Ukrainian regions was calculated based on the data of State Statistics Service of Ukraine on the population of Ukraine and DIRAC data. The figure shows that at least 5 oblast of Ukraine are equipped with MVMs worse than countries of IAEA North Africa

Region. Average number of MVMs in Ukraine is less than in IAEA Eastern Europe and Northern Asia Region. The results of this analysis demonstrate a significant heterogeneity in the access to modern radiotherapy equipment in different regions of Ukraine.

The drop of MVMs number after 2015 (fig. 2) may be explained by the decommissioning of obsolete Co-60 machines. Therefore, the need for a significant

increase in the number of MVMs is an urgent problem in Ukraine.

### Radiotherapy equipment age

According to DIRAC data 61 of 65 Co-60 machines in Ukraine are used during more than 20 years, at that 27 eldest of them must be replaced immediately (marked by dark red on fig. 3).

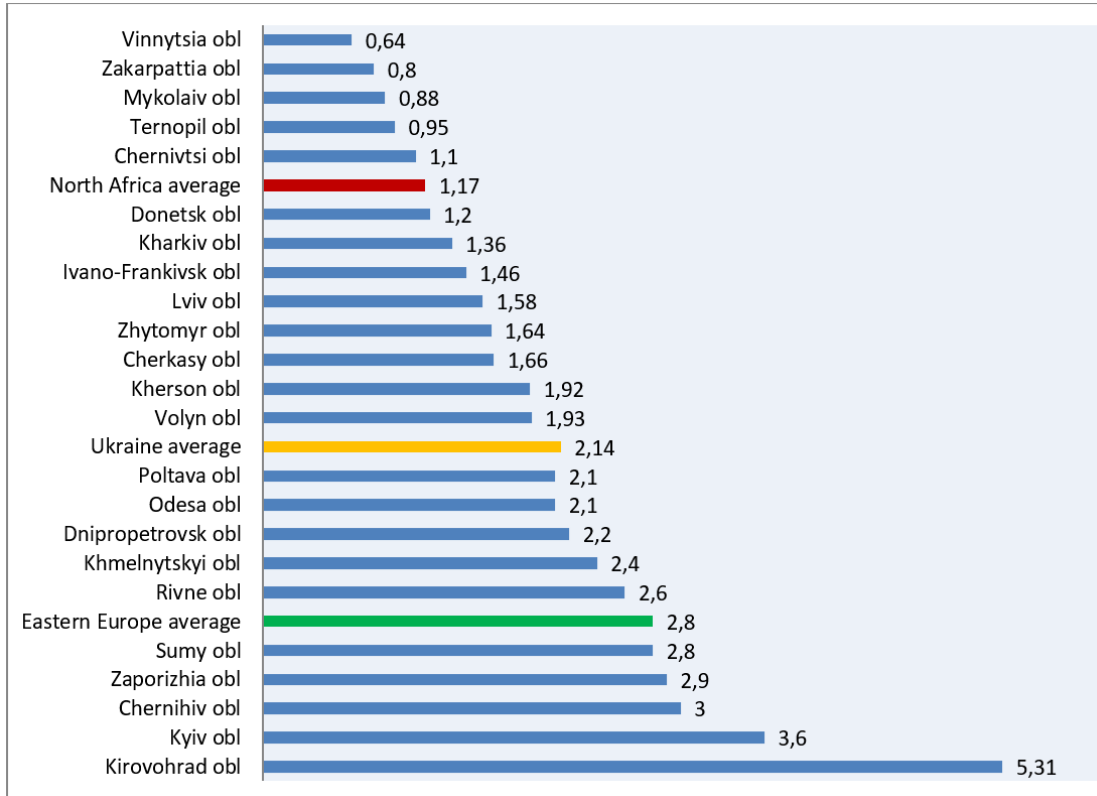


Fig. 1. Number of Radiotherapy Machines per Million People in Ukrainian oblast (DIRAC IAEA, 2018)

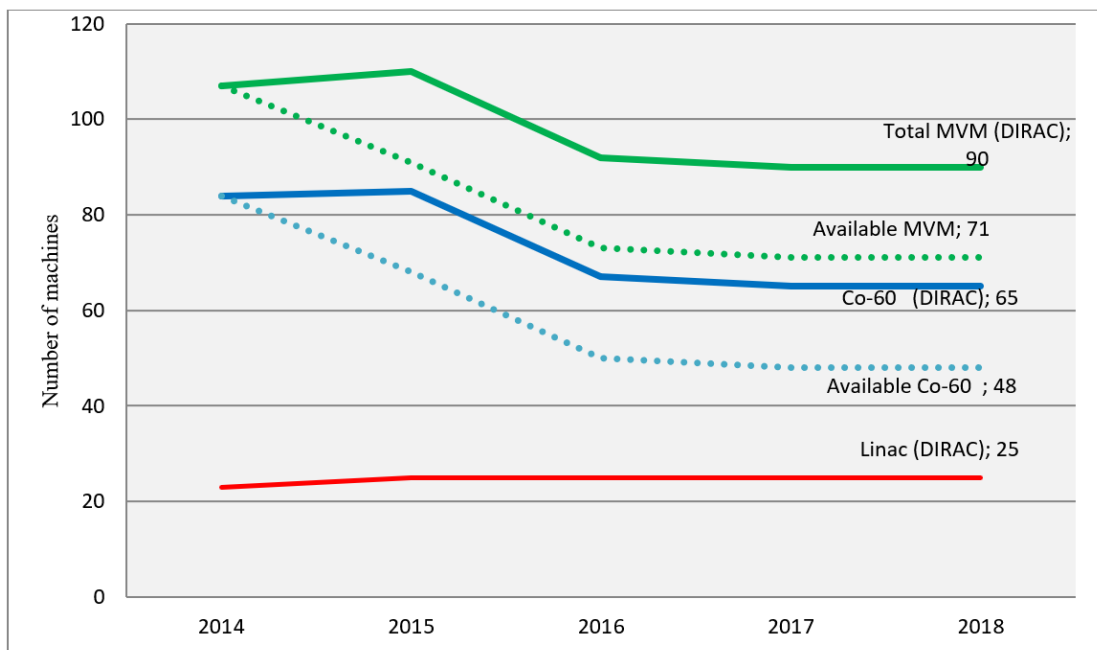
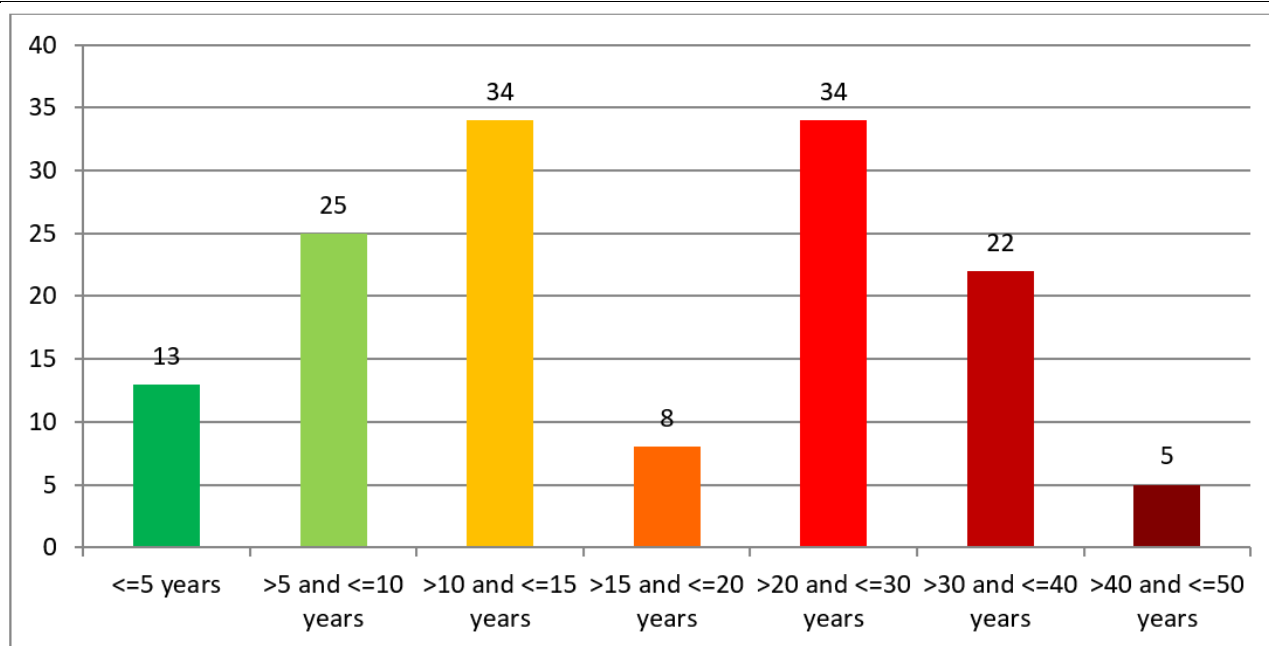


Fig. 2. Changes of number of Radiotherapy Machines in Ukraine during 5 years (DIRAC IAEA, 2018)



**Fig. 3.** Status of Radiation therapy Equipment in Ukraine according to age categories (2019) and appropriate working Radiotherapy megavoltage machines of different age

#### Ratio "Linacs to Co-60 machines"

Linac-based and Co-60-base technologies are different in infrastructure and maintenance, dosimetry, shielding requirements, staffing, costs, security, patient throughput and clinical use [16]. In clinical use, more complex treatment techniques are easier to achieve with

linacs. Linac-based technologies are more flexible, controlled and secure. That's why High income countries seek for total replacement of Co-60 units by linacs (fig. 4, 5).

As for low- and middle-income countries there is no simple answer to the question what is more preferable for radiotherapy – Co-60 machines or linacs? In fact a

combination of both technologies may be proposed for low- and middle-income countries.

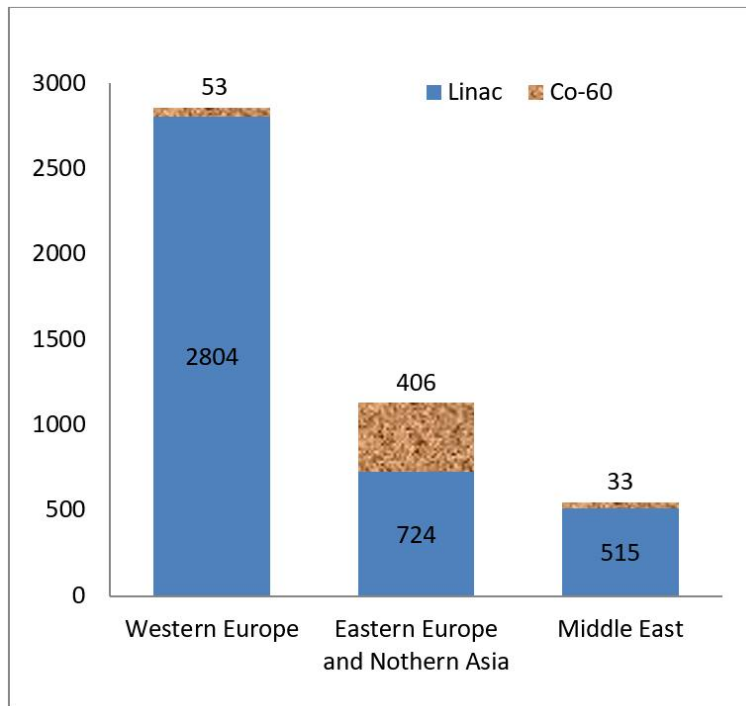


Fig. 4. Ratio "Linacs to Co-60 units" for Western Europe, Eastern Europe and Northern Asia and Middle East IAEA Regions

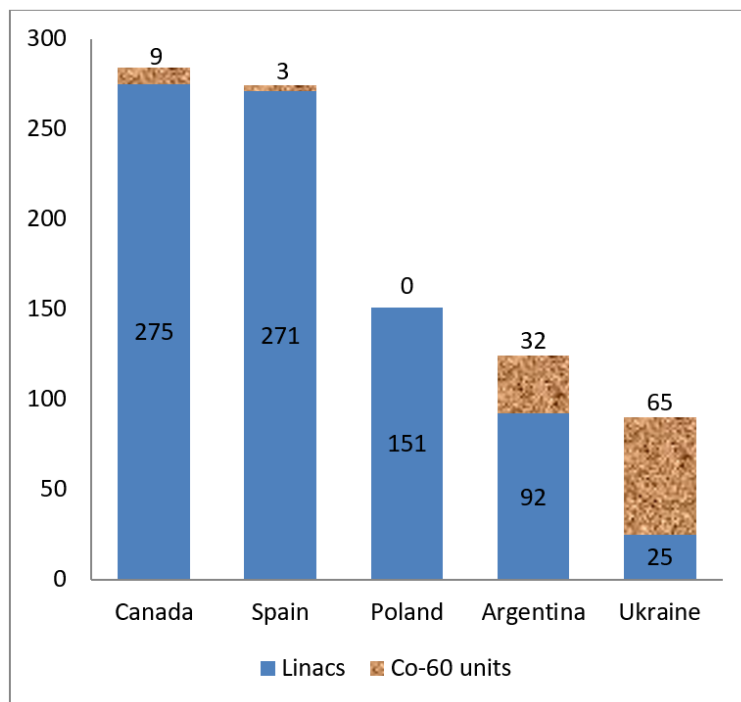


Fig. 5. Ratio "Linacs to Co-60 units" for countries comparable to Ukraine on population

As shown on fig. 4 qualitative ratio "Linacs to Co-60 units" for IAEA region Eastern Europe and Northern Asia is 36% to 64%. Among 406 Co-60 units used in all this region 237 machines are in Russia (58%), 65 machines in Ukraine (16%), 30 machines in Kazakhstan (7%). This fact proves that the largest post-Soviet countries continue to use many old soviet Co-60 machines and replace them on linacs very slowly. Both Russia and Belarus have 53% of Co-60 units, Kazakhstan – 67% and Ukraine – 72%, so,

unfortunately, here Ukraine shows the greatest backlog. It indicates significant technological problems in Ukrainian radiation medicine.

Fig. 5 demonstrates essential differences of ratio "Linacs to Co-60 units" among countries comparable to Ukraine on population (near 40 million inhabitants). Ukraine has almost three times fewer radiotherapy machines than in Canada and Spain. The qualitative ratio "Linacs to Co-60 units" for Ukraine in comparison with

these countries seems catastrophic. But Ukraine is so unique country which continues to keep existing level of radiotherapy technologies with GNI 5 time less than in Poland. It's clear that further progress of Ukraine in area of radiotherapy is impossible without appropriate economic growth.

### Level of Co-60 sources activity

Considering that Co-60 machines are the most prevalent in Ukraine, an important issue is to control the

activity and dose rate of Co-60 sources that have a decay half-life time of 5.27 years. It's known [17] that if Co-60 source Dose rate became less than 0.4 Gy/min, this source need to replace and it can't be used more for radiation treatment. According to information collected by Central Laboratory of Radiation Safety and Medical Dosimetry Equipment, Grigoriev Institute for Medical Radiology NAMS of Ukraine and reported by Head of laboratory Dr .L. Stadnyk, Co-60 sources in 23 Ukrainian treatment machines now have Dose rate <0.4 Gy/min and must be replaced urgently (fig. 6).

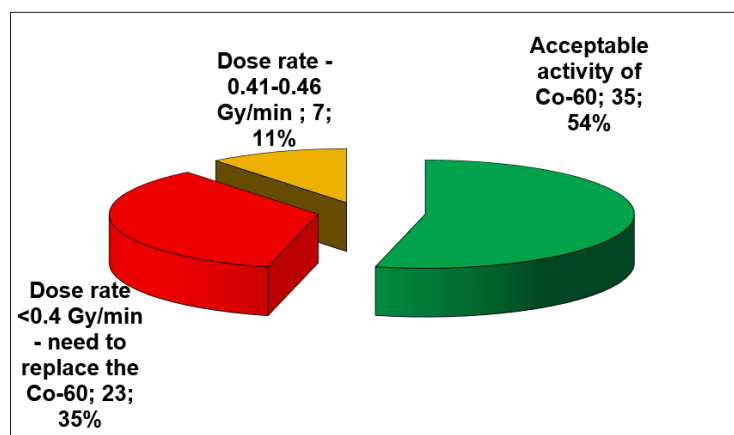


Fig. 6. Results of estimation Co-60 source Dose rate for Co-60 machines used in Ukraine (2019)

It's 35% of total number of MVMS in Ukraine. So, this fact is the reason for immediate source reloading in modern Co-60 machines, but no sense to reload old machines (fig. 3) because of their unreliability and technical backwardness.

### Conclusion and perspectives of further development

The main actual aspects of technical status of equipment for External-beam radiation therapy in Ukraine were discussed. Existing radiotherapy facilities were

analyzed from the point of view of real needs and possibilities of Ukrainian radiation oncology. As a conclusion, the results of this analysis demonstrate a significant heterogeneity in the access to modern radiotherapy equipment in different regions of Ukraine. Use of 90 MVMS covers only 45% needs of Ukrainian population in radiation treatment. The quantitative analyses of used radiotherapy equipment demonstrate its significant technical backwardness. The results of this analysis may be used as technical recommendations for improvement of radiotherapy facilities in Ukraine.

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**АНАЛІЗ СТАНУ РАДІОТЕРАПЕВТИЧНОГО ОБЛАДНАННЯ В УКРАЇНІ**

**Предметом** дослідження в статті є огляд та аналіз існуючих радіотерапевтичних технологій, доступності та ефективності використання сучасного радіотерапевтичного обладнання в регіонах України у відповідності з тенденціями розвитку променевої терапії в Європі. **Мета** роботи – аналіз поточного стану радіотерапевтичного обладнання в Україні, виявлення шляхів розширення його застосування. В статті вирішуються наступні **завдання**: аналіз розподілу радіотерапевтичних апаратів в Україні, визначення кількості радіотерапевтичних апаратів на мільйон населення для всіх областей та потреб радіотерапевтичних центрів України у високочастотних апаратах конформного опромінення. Використовуються такі **методи**: аналіз документальних даних, порівняння, узагальнення. Отримано наступні **результати**: розраховано, що відповідно до вимог МАГАТЕ, необхідна кількість мегавольтних радіотерапевтичних апаратів в Україні має бути близько 200. Використання 90 апаратів покриває лише 45% потреб населення України в променевому лікуванні. За даними DIRAC 61 з 65 машин Co-60 в Україні використовуються протягом понад 20 років, джерела Co-60 у 23 цих машинах зараз мають дозу, меншу, ніж 0,4 Гр / хв, і їх необхідно терміново замінити. **Висновки**: обговорено актуальні аспекти технічного стану обладнання для променевої терапії в Україні. Існуючі засоби променевої терапії були проаналізовані з точки зору реальних потреб та можливостей української радіаційної онкології. Як висновок, результати цього аналізу демонструють значну неоднорідність доступу до сучасного радіотерапевтичного обладнання в різних регіонах України. Якісний аналіз використаного радіотерапевтичного обладнання свідчить про його значну технічну відсталість. Результати цього аналізу можуть бути використані як технічні рекомендації щодо вдосконалення радіотерапевтичних установ в Україні.

**Ключові слова**: променеве лікування зовнішнім пучком; мегавольтні апарати; лінійний прискорювач.

## АНАЛИЗ СОСТОЯНИЯ РАДИОТЕРАПЕВТИЧЕСКОГО ОБОРУДОВАНИЯ В УКРАИНЕ

**Предметом** исследования в статье является обзор и анализ существующих радиотерапевтических технологий, доступности и эффективности использования современного радиотерапевтического оборудования в регионах Украины в соответствии с тенденциями развития лучевой терапии в Европе. **Цель** работы – анализ текущего состояния радиотерапевтического оборудования в Украине, выявление путей расширения его применения. В статье решаются следующие **задачи**: анализ распределения радиотерапевтических аппаратов в Украине, определение количества радиотерапевтических аппаратов на миллион населения для всех областей и потребностей радиотерапевтических центров Украины в высокоточных аппаратах конформного облучения. Используются следующие **методы**: анализ документальных данных, сравнение, обобщение. Получены следующие **результаты**: рассчитано, что в соответствии с требованиями МАГАТЭ необходимое количество мегавольтных радиотерапевтических аппаратов в Украине должно быть около 200. Использование 90 аппаратов покрывает лишь 45% потребностей населения Украины в лучевом лечении. По данным DIRAC 61 из 65 машин Co-60 в Украине используются в течение более 20 лет, источники Co-60 в 23 этих машинах сейчас имеют дозу, меньше, чем 0,4 Гр / мин, и их необходимо срочно заменить. **Выводы**: обсуждались актуальные аспекты технического состояния оборудования для лучевой терапии в Украине. Существующие средства лучевой терапии были проанализированы с точки зрения реальных потребностей и возможностей украинской радиационной онкологии. Как вывод, результаты этого анализа демонстрируют значительную неоднородность доступа к современному радиотерапевтическому оборудованию в разных регионах Украины. Качественный анализ используемого радиотерапевтического оборудования свидетельствует о его значительной технической отсталости. Результаты этого анализа могут быть использованы как технические рекомендации по совершенствованию радиотерапевтической учреждений в Украине.

**Ключевые слова:** лучевое лечение внешним пучком; мегавольтные аппараты; линейный ускоритель.

### *Бібліографічні описи / Bibliographic descriptions*

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