International Journal of Science and Research (IJSR)
ISSN: 2319-7064
Impact Factor 2024: 7.101

Photobiological Effects of LED Lamps in Nail Services: Risks and Safety Considerations

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Abstract: ***The study aims to systematize and critically interpret the existing body of scientific data on the photobiological effects of UV/LED radiation to construct an integral, multilevel risk assessment. A systematic search and analytical processing of the literature were performed, covering in vitro experiments, physical-dosimetric measurements, clinical observations, and industry analytical reports. It was established that the emission of the lamps under consideration falls predominantly within the UVA range (320-400 nm), while irradiance varies between models by more than 26-fold (0,6-15,7 mW/cm²), which makes the reduction of risk assessment to exposure time alone methodologically untenable. In vitro data demonstrate the induction of reactive oxygen species, accompanied by genotoxic DNA damage (8-oxoguanine) and the formation of a specific C:G>A:T mutational signature associated with carcinogenesis. Clinical reports include cases of squamous cell carcinoma in individuals with prolonged use of UV lamps. Despite a likely low average population risk, the cumulative absorbed dose with regular operation of devices with high and unregulated variability of power output forms a significant genotoxic and carcinogenic risk for individual users, which is currently underestimated. The information presented in this work will be of interest to nail service specialists, dermatologists, and organizations responsible for public health and standardization.***

Keywords: UVA radiation, LED lamps, nail service, photobiology, carcinogenic risk, DNA damage, squamous cell carcinoma, dosimetry, safety, keratinocytes.

1. Introduction

The nail service industry is a rapidly growing segment of the global economy. As of 2024 estimates, the global market for nail care products reached USD 24.56 billion, with a projected compound annual growth rate (CAGR) of 5.01% through 2032 [1]. In parallel, the market for salon services per se was valued at USD 8.8 billion, with an expected increase to 13.7 billion by 2034 (CAGR 4.5%) [2]. The principal driver of expansion is the proliferation of durable gel coatings, the polymerization of which requires specialized lamps emitting in the ultraviolet range. In particular, UV gel-based services exhibit the highest growth rates in the U.S. market, indicating the foundational role of the corresponding technologies in the contemporary business model of the industry [3]. The scale of involvement and the regularity of procedures underscore the public relevance of assessing their safety, since millions of clients and technicians are systematically exposed to UV radiation [14].

Despite widespread use, no consensus has been reached regarding the long-term risks of UV/LED lamp use: the available evidence base is heterogeneous. On the one hand, clinical case reports of squamous cell carcinoma and actinic keratosis of the skin of the hands have accumulated in patients with many years of regular gel manicures [4]. These observations imply a possible causal relationship between cumulative exposure to UV radiation from lamps and the development of cutaneous neoplastic lesions. On the other hand, studies based on mathematical modeling and assessment of mean doses often conclude that the carcinogenic risk for the general population is negligible or acceptably low. A methodological gap emerges: there is no unified conceptual framework capable of reconciling compelling molecular evidence of cellular damage obtained under in vitro conditions [8] with the equivocal results of clinical observations and population-based calculations.

The objective of the study is to systematize and analyze the accumulated data on the photobiological effects of UV/LED radiation in nail services with the formation of a comprehensive multi-level risk assessment.

The scientific novelty of the work lies in attempting, within a single research framework, to integrate results from four disciplinary domains- physical dosimetry, molecular and cellular biology, clinical dermatology, and epidemiological modeling- to construct a holistic picture of risks.

The author's hypothesis is that, despite the low magnitude of risk associated with a single polymerization session, multi-year dose accumulation against the background of high and poorly controlled variability of device irradiance forms a significant genotoxic and carcinogenic risk. The latter is systematically underestimated in population models due to averaging of exposure parameters and the neglect of extreme exposure scenarios.

2. Materials and methods

The study was conducted as a systematic review with a critical analysis of the scientific literature. To build the empirical and analytical base, a targeted search was performed in peer-reviewed scientometric resources Scopus, Web of Science, and PubMed, as well as in academic repositories and reports of leading analytical agencies. Publications primarily from the last years were included in the corpus to ensure maximal data relevance.

The source base was systematized along four complementary directions to obtain a structured and multifaceted view of the problem. First, in vitro experimental studies- works focused on cellular and molecular mechanisms of damage under exposure to UV emitters in human cell cultures (keratinocytes, fibroblasts)- were used as the primary material for analyzing genotoxic and cytotoxic effects. Second,

physico-dosimetric studies- publications with spectral characterization of sources, measurement of irradiance, and dose calculations for commercially available UV/LED lamps- formed the basis for assessing the physical parameters of exposure. Third, clinical studies and reviews- clinical observations (case reports) describing skin cancer cases associated with the use of UV lamps, as well as systematic reviews that summarize and critically evaluate clinical risks—were key for analyzing debates on potential carcinogenicity. Fourth, industry and analytical reports- materials from leading agencies such as Grand View Research and Global Market Insights containing data on the size, structure, and growth dynamics of the nail service market- were used to contextualize the scale of the problem and substantiate its relevance.

The integration of results from these heterogeneous bodies of sources made it possible to obtain a holistic picture: from the physical foundations and molecular mechanisms of action to clinical manifestations and practical recommendations.

3. Results and Discussion

Lamps used for the polymerization of gel coatings emit predominantly in the UVA region of the ultraviolet spectrum (320-400 nm), which is classified as a confirmed human carcinogen [12]. Modern light-emitting diode systems produce a narrower emission band with maxima in the 375-425 nm range, whereas earlier devices based on cold-cathode fluorescent lamps (CCFL) generate a broader spectrum covering 300-410 nm [5].

The biological consequences of this circumstance are fundamental. Unlike the UVA quantum, which is absorbed mainly in the epidermis and is responsible for solar erythema, the longer-wavelength UVA radiation has increased penetrating capability: it reaches the basal layer of the epidermis, which contains stem cells, and the dermis. In these tissue compartments, UVA initiates photochemical processes leading to DNA damage in keratinocytes and fibroblasts, as well as to the degradation of structural proteins- collagen and elastin- which underlies premature skin aging (photoaging) [7].

One of the most alarming observations of dosimetric studies is the extreme inter-model heterogeneity of UV power even within a single city. In a study in which 17 different lamps from 16 salons were tested, the range of UVA irradiance levels recorded was from 0.6 mW/cm² to 15.7 mW/cm² [5], that is, more than a 26-fold difference in the intensity of exposure to the client's skin.

Such dispersion effectively invalidates the idea of a standard procedure and prevents risk assessment based solely on exposure duration. The integral dose (J/cm²) is defined as the product of power (W/cm²) and time (s). Consequently, at a fixed polymerization time, for example 8 minutes, the actual received dose may differ by a factor of 26 depending on the specific device. A client in one salon may receive a biologically insignificant exposure, whereas in another- under an apparently identical protocol- be subjected to an exposure level sufficient to induce DNA damage. This indicates a substantial gap in the regulation and standardization of industry equipment: neither the technician nor the client is typically aware of the actual power of the lamp in use.

An immediate consequence of such variability is a sharp divergence in the rate of cumulative dose accumulation. Calculations based on measured irradiance levels demonstrate: to reach a dose sufficient to induce DNA damage, with a lamp of minimum irradiance (0.6 mW/cm²) more than 200 salon visits would be required, whereas at the maximum recorded irradiance (15.7 mW/cm²) the hazardous threshold is reached after only eight visits [5]. Another study showed that in less than 10 minutes of exposure the hands can receive a dose equivalent to the recommended daily limit for workers who spend a full working day outdoors [4]. Thus, even short but regular sessions can make a significant contribution to the total dose burden on the skin (table 1).

Table 1. Comparative dosimetric parameters of commercial UV/LED lamps (compiled by the author based on [5]).

Parameter	Fluorescent (CCFL)	LED
Wavelength range	300-410 nm	375-425 nm
Peak emission	Broad spectrum	375 nm, 385 nm
Irradiance range	Varies, within the overall range	Varies, within the overall range
Overall range (all types)	0.6-15.7 mW/cm2	0.6-15.7 mW/cm2
Typical curing time	120-180 s	30-60 s
Estimated session dose*	0.07-2.83 J/cm2	0.02-0.94 J/cm2

**The estimated session dose (per layer) is based on the minimum and maximum irradiance values and the typical curing time.*

Below, in Figure 1, typical emission spectra of LED and fluorescent UV lamps will be presented [5].

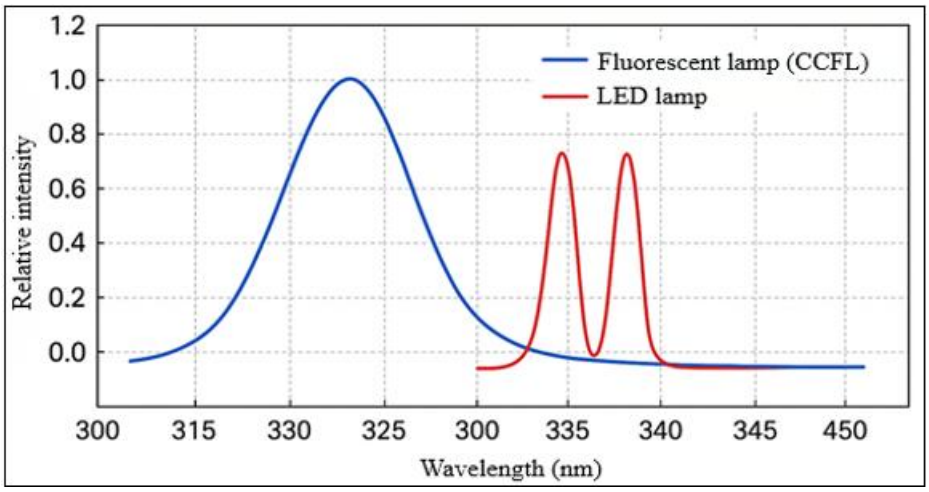

Figure 1: Typical emission spectra of LED and fluorescent UV lamps (compiled by the author based on [5]).

Whereas UVB quanta can be directly absorbed by DNA, the damaging action of UVA is mediated predominantly indirectly. UVA energy is captured by endogenous photosensitizers of skin cells- riboflavin, porphyrins, and others- which initiates a cascade of photochemical transformations and leads to excessive formation of reactive oxygen species (ROS) [8]. ROS include the superoxide anion, hydrogen peroxide, and the highly reactive hydroxyl radical. The resulting oxidative stress causes extensive damage to cellular macromolecules: lipid peroxidation of membranes, protein denaturation, and, most critically, chemical modifications of DNA nitrogenous bases. In addition, ROS disrupt mitochondrial functions, exacerbating redox imbalance and potentially initiating the apoptosis program.

Direct evidence of the genotoxicity of manicure lamp radiation has been obtained in in vitro experiments on human (epidermal keratinocytes, fibroblasts) and mouse cell cultures. It has been established that exposure to commercial UV nail devices induces specific oxidative DNA damage, primarily the formation of 8-oxo-7,8-dihydroguanine (8-oxoG) [8]- one of the most prevalent and well-studied markers of oxidative damage.

A critical feature of 8-oxoG is that during replication DNA polymerase tends to mispair it with adenine instead of cytosine. If such an error is not timely corrected by the base excision repair system (BER), in the next cell cycle it becomes fixed as a transition: the original guanine-cytosine pair (G:C) is replaced by thymine-adenine (T:A). Analysis of somatic mutations in irradiated cells reveals a dose-dependent increase precisely in these substitutions, forming the mutational signature C:G>A:T (when projected onto the coding strand) [8].

Detection of this characteristic mutational signature serves as a compelling molecular fingerprint directly linking a specific physical agent (UVA radiation) to a defined type of genetic damage. This concerns signature SBS18 from the COSMIC catalogue, which correlates with damage induced by reactive oxygen species and is detected across numerous tumor types [11]. Thus, a continuous and biologically coherent causal sequence is established: UVA radiation from the lamp → intracellular generation of ROS → formation of 8-oxoG in DNA → replicative errors → mutations of the C:G>A:T type → increased probability of malignant transformation. The discussion of risks is thereby shifted from the realm of bare statistical associations to the plane of experimentally validated molecular mechanisms. In addition to the genotoxic component, UV-lamp radiation demonstrates pronounced cytotoxicity, that is, the ability to induce cell death. It has been shown that a single 20-minute irradiation leads to the elimination of about 20-30% of cells in culture, whereas three consecutive 20-minute exposures increase the proportion of dead cells to 65-70%. Critically, the population that survives such exposure retains signs of mitochondrial dysfunction and DNA damage. A critically dangerous configuration arises: cells with mutations that bypass apoptosis can initiate clonal expansion and give rise to a malignant clone (figure 1).

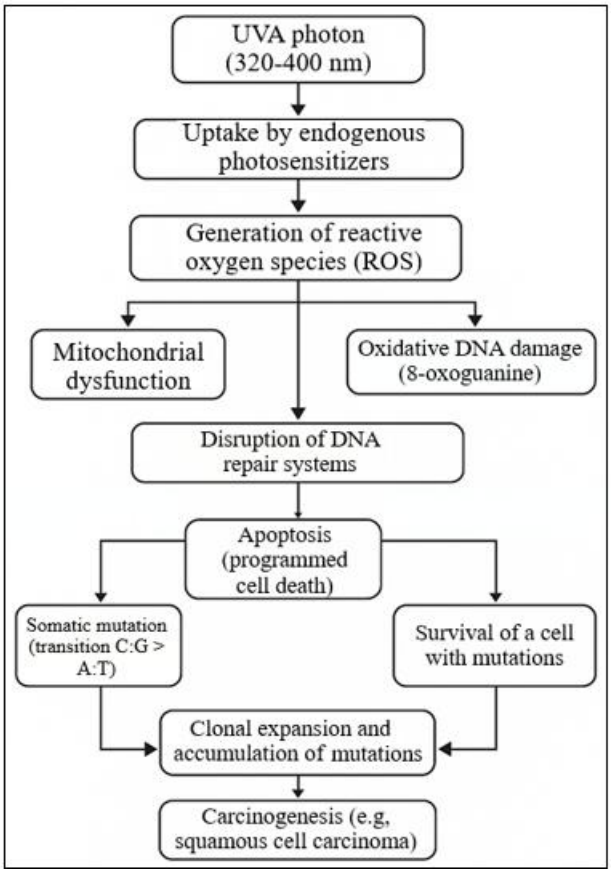

Figure 2: Cascade of molecular events in a keratinocyte under the influence of UVA radiation (compiled by the author based on [8]).

The discussion of the possible carcinogenic potential of UV/LED lamps remains the most acute and polarizing topic: the body of available evidence effectively splits into two mutually opposing lines of argumentation.

The pro risk position relies primarily on clinical observations of nonmelanoma skin cancer in individuals with a long history of UV lamp use. As early as 2009, Macfarlane and Alonso first described two episodes of squamous cell carcinoma (SCC) on the dorsal surface of the hands in women who regularly underwent UV manicure [4]. Another report described the development of 7 foci of SCC on the fingers and toes over a 5-year period. Although these cases by themselves do not allow etiological causality to be established with absolute certainty, the concordance of tumor localization with chronically irradiated areas lends the hypothesis biological plausibility. Furthermore, it has been shown that with higher-power lamps the threshold dose required to induce DNA damage may accumulate after as few as 8 visits, which challenges the perception of safety even with a relatively short exposure history [5].

At first glance, the apparent contradiction between clinical observations and population models is a typical example of the averaging fallacy: these are not mutually exclusive but complementary perspectives on the same problem.

Models such as the Diffey approach inevitably operate with mean quantities- mean radiant power, mean session frequency, and population-averaged genetic susceptibility. Within this framework they accurately describe the fate of the average user and show that for the population as a whole the incremental contribution to risk is small.

Clinical practice, by contrast, deals with individual patients who may present a configuration of elevated risk factors: high procedure frequency (for example, weekly sessions over many years). Use of sources with high radiation intensity (falling at the upper end of a 26-fold variability); individual predisposition (fair skin phototype, genetic variants, immunocompromise).

Therefore, the correct interpretation is not to choose one side, but to acknowledge different levels of analysis: the average population risk is low, whereas for subgroups with high cumulative dose and/or biological vulnerability it can be substantially higher and clinically significant. The current debate suffers from insufficient risk stratification, which fuels its polarization.

For greater clarity, Table 2 presents an analysis of arguments regarding carcinogenic risk.

Table 2: Summary analysis of arguments in debates on carcinogenic risk (compiled by the author based on [4, 5, 6, 8])

Type of evidence	Arguments for a meaningful risk (Pro)	Arguments for a low/negligible risk (Contra)
Clinical reports	Presence of cases of SCC on the hands in patients with a long history of UV-manicure.	Absence of large epidemiological studies demonstrating an increase in incidence.
Molecular in vitro data	Proven mechanism of genotoxicity: ROS generation, DNA damage (8-oxoG), mutational signature C:G>A:T.	In vitro data may not fully reflect processes in living tissue with its protective mechanisms.
Mathematical modeling	-	Models indicate that hundreds of thousands of users are required for 1 additional cancer case.
Dosimetric studies	Large (up to 26-fold) variability in lamp power, possibility of rapid accumulation of a hazardous dose (within 8 visits).	The mean dose per session with most lamps remains low.

Further, Figure 3 identifies the factors determining individual cumulative risk.

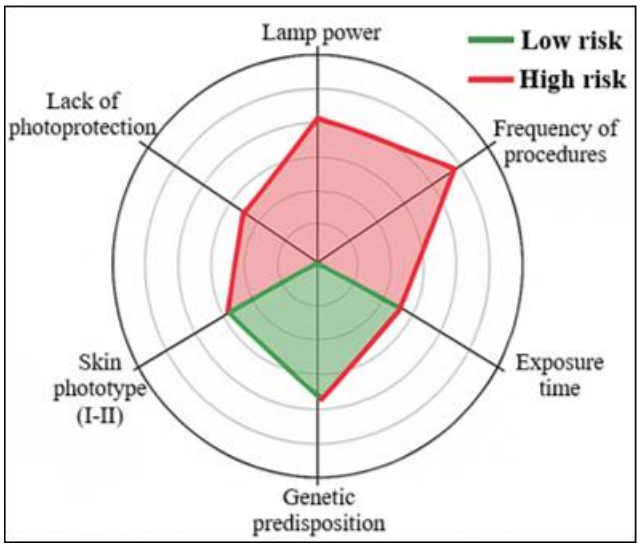

Figure 3: Factors determining individual cumulative risk (compiled by the author based on [9, 10, 17]).

Relying on data on photobiological mechanisms and dosimetric characteristics of radiation, scientifically grounded approaches can be formulated to reduce potential risks when working with UV/LED lamps:

1) Use of sunscreens: Since the principal damaging agent is the UVA component of the spectrum, the basic measure should be the application of a broad-spectrum photoprotector with an SPF of at least 30. The formulation is applied to the skin of the hands and fingers (excluding the nail plate) 20-30 minutes before the procedure to allow time for the active ingredients to form a continuous protective layer. Preparations with physical (mineral) filters- zinc oxide and titanium dioxide- are preferable, as they provide stable shielding of UVA rays [6].
2) Use of protective gloves: An equivalent or additionally reinforcing strategy is the use of special fingerless gloves made of fabrics with verified UV protection (UPF 50+). Such products cover almost the entire skin surface of the hands and fingers, leaving only the nail plates exposed, and are capable of blocking up to 99% of incident ultraviolet radiation, which makes them a simple and reliable preventive measure [4].

Table 3 summarizes the safety recommendations.

Table 3: Matrix of practical recommendations for ensuring safety (compiled by the author based on [13, 16, 18]).

Process participant	Recommended actions	Rationale
Client	• Apply sunscreen (SPF 30+) or use UV-protective gloves. • Reduce the frequency of procedures, introduce breaks. • Regularly examine the skin of the hands for neoplasms.	Reduction of the UV dose reaching the skin. Lower cumulative dose. Early detection.
Nail technician	• Inform clients about precautions. • Use modern LED lamps. • Strictly adhere to the recommended polymerization time.	Improved client awareness and safety. Shorter exposure time. Prevention of excessive exposure.
Salon owner / Industry	• Invest in high-quality, certified equipment (LED). • Implement client information standards. • Require manufacturers to specify lamp spectral characteristics and power.	Positioning safety as a competitive advantage. Increased transparency and creation of a basis for standardization and regulation.

A cumulative analysis of dosimetric measurements, biological markers, and clinical observations indicates that, with adherence to protocols (interprocedural interval of 3-4 weeks) and the use of properly functioning, high-quality equipment, the polymerization of gel coatings is characterized by a favorable safety profile. Risk assessment associated with the use of UV/LED lamps indicates a low level. The implementation of effective photoprotection measures- the application of a broad-spectrum SPF cream immediately before the procedure and/or the use of gloves with verified UV-blocking capability- allows residual risks to be virtually completely mitigated and maintains long-term client safety.

4. Conclusion

The conducted synthesis of scientific data allows the formulation of several key theses. First and foremost, UV/LED units used in nail services are sources of photobiologically significant radiation in the UVA range which, as shown in in vitro experiments, consistently induces oxidative stress, genotoxic DNA damage, and cytotoxic effects in human skin cells. The established cascade of damage, accompanied by the emergence of a specific mutagenic signature C:G>A:T, provides a biologically plausible basis for potential carcinogenesis.

The empirical indicators under consideration should be interpreted through the lens of real-world practice. For clients attending procedures at a scheduled periodicity (approximately once every 3-4 weeks), the cumulative dose of skin irradiation proves to be substantially below thresholds associated with clinically significant damage. In other words, under typical use regimens, the actual exposure is far from levels that would raise concern.

The stated research objective- to systematize and critically compare heterogeneous datasets- has been achieved. An integrated risk assessment framework is proposed that unifies findings from laboratory, clinical, and epidemiological observations, resolving the apparent contradictions among them. Thus, the focus shifts from the general question of how hazardous lamps are as a class to the analytically more productive question of which parameters- radiation spectrum, dose and duration, skin phototype, comorbid conditions, and user behavior- determine individual risk.

The practical significance of the work lies in establishing an evidence base for updating safety standards in the nail industry. The study demonstrates that, with the observance of simple and accessible precautions, the procedure is completely safe. The use of broad-spectrum photoprotection (SPF products) and/or gloves with UV filtering constitutes a sufficient and effective strategy for reducing individual risks to minimal levels. These recommendations are relevant for the development of training modules for practitioners, the preparation of educational materials for consumers, and may serve as a methodological basis for introducing mandatory equipment labeling indicating its dosimetric characteristics. The conclusions are addressed to nail service specialists, dermatologists, and organizations engaged in public health and consumer protection.

References

[1] Nail Care Products Market Size, Share, Trends | Report [2032] - Fortune Business Insights [Electronic resource]. - Access mode: https://www.fortunebusinessinsights.com/nail-care-market-106149 (date of access: 10.08.2025).
[2] Nail Salon Market Size, Share & Analysis Report, 2025 - 2034 [Electronic resource]. - Access mode: https://www.gminsights.com/industry-analysis/nail-salon-market (date of access: 10.07.2025).
[3] US Nail Salon Market Size & Outlook, 2023-2030 [Electronic resource]. - Access mode: https://www.grandviewresearch.com/horizon/outlook/nail-salon-market/united-states (date of access: 12.08.2025).
[4] Williams E. A., Kuschner S. H. Ultraviolet nail lamps and squamous cell carcinoma: cause and effect, or not?—a case report //Open Journal of Orthopedics. - 2021. - Vol. 11 (11). - pp. 335-339.
[5] Nailing Down on the Ultraviolet Exposure Occurring During the Curing and Drying of a Manicure [Electronic resource]. - Access mode: https://www.aimatmelanoma.org/nailing-down-on-the-ultraviolet-exposure-occurring-during-the-curing-and-drying-of-a-manicure/ (date of access: 14.08.2025).
[6] Verma K. K. et al. Safety information and adverse event profiles of ultraviolet nail lamps: a commercial website analysis //Baylor University Medical Center Proceedings. - Taylor & Francis, 2025. - Vol. 38 (2). - pp. 1-5.
[7] Can Ultraviolet Nail Salon Lamps Give You Skin Cancer? [Electronic resource]. - Access mode: https://health.clevelandclinic.org/can-ultraviolet-nail-salon-lamps-give-you-skin-cancer (date of access: 14.08.2025).

[8] Lopes A., Pereira P., Oliveira H. Cytotoxic effects of a LED/UV nail polish dryer in human keratinocytes //Toxicology in Vitro. - 2025. - pp.1-3.
[9] Determining the Action Spectrum of UVR-Induced Mitochondrial [Electronic resource]. - Access mode: https://theses.ncl.ac.uk/jspui/bitstream/10443/2219/1/Latimer%20JA%2013.pdf (date of access: 14.06.2025).
[10] Zhivagui M. et al. DNA damage and somatic mutations in mammalian cells after irradiation with a nail polish dryer //nature communications. - 2023. - Vol. 14 (1). - pp. 1-5.
[11] Beylin D. et al. Assessing the Health Implications of UV/LED Nail Lamp Radiation Exposure During Manicure and Pedicure Procedures: A Scoping Review //International Journal of Dermatology. - 2025. - Vol. 64 (4). - pp. 659-666.
[12] Marciniak A. et al. The effect of sunlight and UV lamps on EPR signal in nails //Radiation and Environmental Biophysics. - 2019. - Vol. 58 (2). - pp. 287-293.
[13] Tkatchenko N. et al. EPR Dosimetry in Human Fingernail: Ultraviolet-Induced Signals. - 2023. https://doi.org/10.21203/rs.3.rs-3748691/v1.
[14] Nail Care Products Market Size, Share & Analysis Report, 2034, [Electronic resource]. - Access mode: https://www.gminsights.com/industry-analysis/nail-care-products-market (date of access: 14.06.2025).
[15] Nail Care Services Market Size, Share | CAGR of 7.7% [Electronic resource]. - Access mode: https://market.us/report/nail-care-services-market/ (date of access: 17.06.2025).
[16] Nail Care Market - Global Industry Analysis and Forecast (2025-2032) [Electronic resource]. - Access mode: https://www.maximizemarketresearch.com/market-report/global-nail-care-market/21902/ (date of access: 06.07.2025).
[17] dos Santos M. A., Correa L. F., Heberlé G. Health and hygiene of skin, hair, nails, and teeth in the space environment: daily challenges //Handbook of Space Pharmaceuticals. - Springer, Cham, 2021. - pp. 1-22.
[18] Hamouda S. A. et al. Ultraviolet radiation: Health risks and benefits //Saudi Journal of Engineering and Technology. - 2022. - Vol. 7 (10). - pp. 533-541.