

UDC 614.485; 614.487
EDN: FUXTBY

PACS: 87.50; 92.60.Sz

Application of UV radiation 222 nm of excimer KrCl lamps for disinfection

L. M. Vasilyak^{1,*}, N. N. Kudryavtsev², S. V. Kostyuchenko³, D. O. Sivin³ and I. S. Timofeev³

¹Joint Institute for High Temperatures of Russian Academy of Sciences, Moscow, 125412 Russia

*E-mail: vasilyak@ihed.ras.ru

²Moscow Institute of Physics and Technology, Moscow Region, Dolgoprudny, 141701 Russia

³NPO "LIT", Moscow Region, Dolgoprudny, 141701, Russia

Received 16.06.2025; revised 15.08.2025; accepted 20.10.2025

The prospects of using UV radiation from 222 nm excimer KrCl lamps for disinfection of air and surfaces are analyzed. The alleged main advantages of 222 nm radiation, which include the ability to disinfect in the presence of humans, and a higher bactericidal efficacy compared to the wavelength of 254 nm, are being tested experimentally. Studies show conflicting results about the safety of such radiation for the skin and for the eyes of mammals. It has been established that there is an effect on tissues, but it has not yet been proven that it is safe with prolonged multiple exposures. Inactivation of viruses and simple bacteriological strains by UV radiation of 222 nm and 254 nm is achieved at similar UV doses, however, UV radiation of 254 nm has a significant advantage for larger objects (endospores, fungi, fungal hyphae). The efficiency of 222 nm UV radiation generation in industrial KrCl lamps is 3–5 %, which is significantly less than for low-pressure mercury and amalgam lamps 30–35 %.

Keywords: air; disinfection; UV radiation; 222 nm.

DOI: 10.51368/2949-561X-2025-5-5-10

Introduction

The COVID-19 pandemic showed that indoor air and surface disinfection is still a critical issue and has prompted renewed investigation of proven germicidal UV disinfection, which effectively lowers airborne pathogen transmission [1]. Low-pressure mercury and amalgam lamps are the primary sources of germicidal UV radiation at 254 nm (UV-254 nm), which affects the DNA and RNA of microorganisms. As an alternative, it is proposed to use UV light between 200 and 235 nm, in particular the 222 nm output of an excimer lamp based on krypton and chlorine (KrCl) with a wavelength of 222 nm (UV-222 nm). It has been reported that for certain microorganisms, UV disinfection at 222 nm is more effective than at 254 nm, and it has been suggested that

disinfection could be performed in the presence of people because the penetration depth of 222 nm radiation in human skin is only a few micrometers, being fully absorbed by the stratum corneum of dead cells and unable to reach the viable cells of the epidermis [1–5]. In this regard, we reviewed studies on the effectiveness of 222 nm UV produced by KrCl excimer lamps for disinfection and assess the safety of using them in the presence of people.

KrCl excimer lamp

Currently, the krypton–chloride (KrCl) excimer lamp, with a primary emission peak at 222 nm, is the most promising source of far germicidal UV radiation [5–10]. The common design of an excimer lamp is a cylindrical, coaxial quartz bulb with inner and outer walls,

filled with krypton plus a trace of chlorine, and fitted with two electrodes: a solid metal tube as the inner electrode and a metal wire cloth as the outer electrode. The barrier discharge in the lamp is created by high-voltage pulses with 4–10 kV amplitude.

The figure shows the spectral emission frequency of a KrCl excimer lamp.

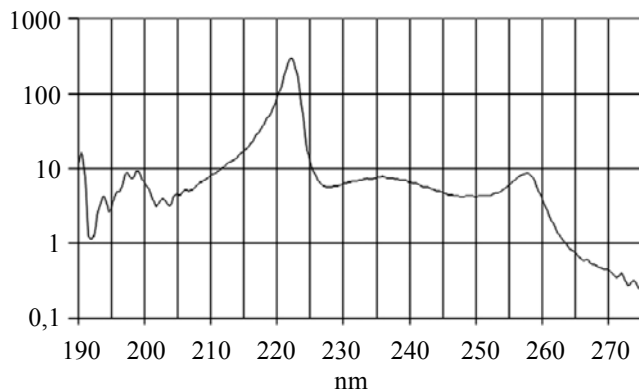


Fig. Distribution of spectral emissive power of KrCl lamp radiation

The majority of the UV radiation power is concentrated around the 222 nm line, showing only minor emissions in the regions below 210 nm and above 230 nm. Some manufacturers add filters that transmit the primary 222 nm line while attenuating other wavelengths. Excimer lamps can reach peak linear electrical powers up to 1 W/cm^2 at high voltage pulse repetition rates (100 kHz), exceeding those of low-pressure mercury vapor lamps but less for amalgam lamps. Power supplies for excimer lamps are more expensive than those for amalgam lamps of comparable power. An undeniable benefit of excimer lamps in specialized environments is the absence of mercury. Although the stated lifespan for KrCl lamps is typically 4,000–5,000 hours, manufacturers generally omit data regarding the degradation of UV radiation output as the lamps approach the end of their service life. For comparison, the service life of low pressure amalgam and mercury lamps is 8,000–16,000 hours, during which UV radiation is guaranteed to decrease by no more than 15 %. The electrical power of series-produced KrCl lamps ranges from 2 W to 800 W, with bulb lengths of 6 to 100 cm [10]. Laboratory devices can reach up to 15 % efficiency for generating 222 nm UV, while industrial lamps typically achieve only 3–5 %, which is less magnitude than the efficiency of

producing 254 nm UV with low pressure mercury and amalgam lamps. High power excimer lamps demand supplementary cooling of the bulb to sustain the manufacturer specified UV radiation and longevity, making reliable operation a complex technical task in real-time use.

Bacteriological action of UV studies with 222 nm wavelength

The primary stated benefit of UV-222 nm radiation disinfection is its ability to effectively inactivate microorganisms and viruses while being safe for the skin and eyes of mammals [2–4, 11–22]. UV-222 nm radiation is significantly absorbed by proteins (by the peptide bonds within them), as well as other biomolecules [13]. Its penetration depth is limited to a few micrometers in the outer layers of dead skin, which is less than that of 254 nm radiation [11, 14]. Given that US regulations specify a maximum daily dose (fluence) of 25 mJ/cm^2 for UV-222 nm is four times greater than the 6 mJ/cm^2 limit for 254 nm, this creates an added incentive for further research. Another concept was that the efficacy of UV-222 nm would surpass that of 254 nm, resulting in lower required doses (fluences) to inactivate microorganisms. However, the inactivation efficiency for various types of bacteria and spores was found to be both greater and lesser compared to that of 254 nm radiation [3, 8, 9, 17, 18]. For the inactivation of the viruses examined, the doses of UV radiation in the range of 200–230 nm were less than those required for UV-254 nm. As the wavelength shortens, the absorption of radiation by proteins rises [8, 9, 11], and the damage to proteins also starts to contribute to the eradication [8, 9, 16].

UV radiation at 222 nm is equally effective as 254 nm in inactivating *Staphylococcus aureus* on model human skin when administered at 254 nm [3, 8, 9]. References [17, 18] demonstrated that both 222 nm and 254 nm UV radiation were equally effective in inactivating a range of bacteria. However, when treating endospores of *Bacillus cereus* and *Clostridium sporogenes*, as well as strains of fungi such as *Aspergillus niger* and *Trichophyton rubrum*, the effectiveness of 254 nm UV radiation was significantly greater than that of 222 nm. For

example, in order to inactivate *Aspergillus niger* spores using 222 nm radiation, a dose of 500 mJ/cm² is required, whereas only half that dose is needed for 254 nm radiation. Fungal growth and hyphae development in *Aspergillus niger* were significantly inhibited at a UV-254 nm dose of 250 mJ/cm², while 222 nm radiation demonstrated only a slight impact on hyphae growth, even at a dose of 1000 mJ/cm² [17, 18].

Variations in the sensitivity of microorganisms to radiation may be influenced by factors such as their size and genome size. Additionally, for viruses, characteristics like a viral envelope (whether they are enveloped or non-enveloped), the thickness of that envelope, and the proteins contained within it may also play a significant role. For example, pigmentation of microorganisms (for some types of fungi) may also be the cause of decreased sensitivity to UV radiation.

Viruses are inactivated by UV radiation in the 200-230 nm range at lower doses compared to UV-254 nm [8, 9, 17, 18]. For example, human coronavirus analogues from the alpha (HCoV-229E) and beta (HCoV-OC43) subgroups were inactivated with an efficiency of 99.9 % at 1.7 and 1.2 mJ/cm² irradiation doses, respectively [5]. These doses are considerably lower than those required for inactivating the SARS-CoV-2 coronavirus at 254 nm. Reference [5] states that 222 nm radiation is effective against viruses and microorganisms smaller than 5 µm. However, it is also indicated that the effectiveness of this radiation on larger objects has not been thoroughly studied. In references [8, 9], comparative data is provided on the inactivation of bacteria and viruses using various UV radiation wavelengths emitted by different excimer lamps. These studies found that while 222 nm and 254 nm UV radiation wavelengths were similarly effective at inactivating bacteria, UV-222 nm was significantly more effective against viruses. Several factors may contribute to the increased sensitivity of bacteriophages to radiation in the 200–240 nm range compared to UV-254 nm [8, 9]. One suggestion is that short-wave UV radiation damages both the viral nucleic acid (DNA or RNA) and the proteins comprising the capsid (viral envelope). These proteins are crucial because they protect the viral nucleic acid and also enable the virus to adsorb (attach) to host

cells, meaning their damage leads to a loss of infectability.

Due to increased absorption and scattering by proteins at shorter wavelengths, the penetration depth into biological tissue decreases [11, 13, 14]. This reduction may, depending on exposure conditions, lead to less effective microorganism inactivation. A study [19] demonstrated that media such as sweat, albumin, and wound effluent significantly reduced the inactivating effect of 222 nm radiation more so than that of 254 nm radiation when irradiating microorganisms. Since airborne microorganisms are typically found in protein-layered aerosols, 222 nm radiation is absorbed strongly than 254 nm. This means that the actual disinfection doses for UV-222 nm in practical applications will be significantly higher than those obtained in ideal laboratory conditions. It is important to note that the bactericidal efficacy of UV-222 nm has only been measured for a limited range of microorganisms. Substantial research is therefore required for a wider range of pathogens, as well as studies on how environmental conditions affect its disinfection efficacy.

Safety of UV radiation with 222 nm wavelength

The safety of UV-222 nm irradiation for human presence has primarily been assessed by evaluating DNA damage in eukaryotic cell cells through in vitro and in vivo models [2, 3, 15]. A study [16] demonstrated that irradiation of human and animal cells induced a small number of DNA dimers (cancer markers), which disappeared within 24 hours. UV radiation at 222 nm produced no erythema, cell death, or inflammatory response, even at the highest exposure levels [16]. However, a study [4] demonstrated that a 40 mJ/cm² dose led to the formation of radical compounds in reconstructed human skin.

Studies [20, 21] revealed a risk of cancer development from exposure to the full spectrum of radiation from a KrCl lamp if an optical bandpass filter is not used to cut off wavelengths shorter and longer than 222 nm. Lamps with filters did not induce elevated levels of DNA dimers (cancer markers) at a daily dose of

23 mJ/cm². The use of such filters will reduce the source's overall radiation intensity and increase equipment costs. Furthermore, the stability of such filters over several thousand hours of operation has not yet been studied

A study [22] demonstrated that UV-254 nm exposure resulted in significantly greater formation of reactive oxygen species and inflammatory responses compared to UV-222 nm. Reactive oxygen species are formed even at doses of 25 mJ/cm², which is a level permitted by US health standards, and can consequently slow skin regeneration for 48 hours. Studies [22] involving long-term (up to 40 days) indirect exposure to 222 nm radiation, at the maximum permissible dose of 25 mJ/cm², revealed minor skin damage. However, these observed damages and morphological skin changes persist, posing a serious long-term risk with periodic exposure, including premature skin aging. The authors of [22] conclude that alterations in skin regeneration mechanisms raise concerns regarding the direct effects of UV-222 nm.

Regarding eyes safety, rat experiments [23] showed that 222 nm UV radiation is absorbed by the outer layers of the corneal epithelium, preventing it from reaching the retina and lens (with slight thinning observed at very high doses). This suggests that serious consequences for humans are unlikely to happen. Research into the effects of far-UV radiation on the eyes is ongoing, and its safety has not yet been definitively established.

Before UV-222 nm can be used in public places with people present, chronic exposure studies must be conducted, specifically including exposure to the eyes and skin. Furthermore, potentially vulnerable groups such as children, the elderly, and individuals with skin or eye diseases, as well as the effects of deep UV radiation on those taking photosensitizing drugs, must also be considered. While studies [24, 25] address this topic, they are not yet conclusive regarding the safety of 222 nm radiation for humans.

Ozone generation by an KrCl excimer lamp

While the KrCl lamp's spectrum (see figure) contains a small amount of radiation

below 200 nm that can generate ozone, the main 222 nm wavelength will contribute insignificantly to the generation. With the use of additional bandpass optical filters, overall ozone generation will be negligible. Pulsed microdischarges, occurring in gaps of approximately 100 µm or more between a metal wire cloth exterior electrode and the surface of a quartz flask, can also be a source of ozone. The amount of ozone generated will depend on the size and number of gaps, voltage amplitude, and lamp power [8, 9, 26]. Some manufacturers have overcome this problem by using a complex and expensive technology: directly printing electrodes onto the quartz to eliminate gaps.

Studies [8, 9, 26] provided estimates for the indoor ozone generation from commercial pulsed KrCl excimer lamps operating at 222 nm. Ozone generation is 0.012 mg/h for a low-power device with a 12 W Ushio Care 222 B1 module. The module contains four KrCl excimer lamps, each equipped with a quartz window and a bandpass filter that emits only UV-222 nm. Even after 24 hours of continuous operation in a 30 m² room, the module's ozone concentration reached only 0.009 mg/m³. This level is undetectable by human senses and significantly lower than the maximum permissible ozone concentration of 0.03 mg/m³ for atmospheric air in populated areas. However, a 70 W KrCl lamp with a wire cloth exterior produced ozone at a rate of 12 mg/h. This would lead to an ozone concentration of 0.36 mg/m³ in a 30 m³ room within one hour, significantly exceeding maximum permissible concentrations. The main reason for the high ozone generation rate is the design of the wire cloth exterior. Consequently, KrCl lamps can generate dangerous ozone concentrations in rooms without ventilation.

Conclusion

Currently, the primary claimed advantage of UV-222 nm from KrCl excimer lamps, its ability to disinfect air and surfaces in the presence of people, is undergoing active testing, but final conclusions are yet to be reached. Studies present conflicting results regarding the safety of such radiation for mammalian skin and eyes. While an effect on tissue has been established, its safety has not yet been proven. Little research has been

conducted on the safety issues associated with chronic exposure. The effects of 222 nm UV radiation on vulnerable groups, such as healthcare workers, children, the elderly, and individuals with skin or eye diseases, have not been addressed.

The bacteriological efficacy of 222 nm UV radiation has no advantage over 254 nm UV radiation from mercury and amalgam lamps. While both types of ultraviolet light achieve similar inactivation rates for airborne viruses and simple bacteria at comparable doses, 254 nm UV offers a significant advantage when disinfecting larger entities (like endospores, fungi, and fungal hyphae). 222 nm radiation is absorbed far more strongly by these proteins than 254 nm radiation because airborne

microorganisms are often encased in protein-rich aerosols or have protein layers. This significantly reduces 222 nm UV's inactivating effect, necessitating practical doses several times higher than laboratory ones, thus negating any advantage compared to UV-254 nm.

Low-pressure mercury and amalgam lamp systems substantially outperform KrCl excimer lamps in terms of energy consumption, efficiency, service life, and cost.

KrCl lamps can produce negative significant concentrations of ozone in the air depending on their design, power, and operating time.

KrCl lamps can only be used for disinfection in special conditions that require the complete absence of people.

REFERENCES

1. Vasilyak L. M., *Plasma Phys Rep.* **47**, 318 (2021).
2. Barnard I. R. M., Eadie E. and Wood K., *Photodermatology, Photoimmunology & Photomedicine* **36** (6), 476–477 (2020). doi: 10.1111/phpp.12580
3. Buonanno M., Ponnaiya B., Welch D., Stanislauskas M., Randers-Pehrson G., Smilenov L. and Brenner D. J., *Radiation Research* **187** (4), 493–501 (2017). doi: 10.1667/rr0010cc.1
4. Yamano N., Kunisada M., Kaidzu S., Sugihara K., Nishiaki-Sawada A., Ohashi H. and Nishigori C., *Photochemistry and Photobiology* **96** (4), 853–862 (2020). doi: 10.1111/php.13269
5. Buonanno M., Welch D., Shuryak I. and Brenner D. J., *Sci. Rep.* **10** (1), 10285 (2020). doi: 10.1038/s41598-020-67211-2
6. Sosnin E. and Tarasenko V., *Photonics*, No. 1/49/, 60–69 (2015).
7. Lomaev M. I., Skakun V. S., Sosnin E. A., Tarasenko V. F., Shitts D. V. and Erofeev M. V., *Phys. Usp.* **46**, 193–209 (2003).
8. Sosnin E. A., Skakun V. S., Panarin V. A., Avdeev S. M. and Sorokin D. A., *Journal of Optical Technology* **88** (10), 587–592 (2021).
9. Sosnin E. A. and Zhdanova O. S., *Quantum Electronics* **50** (10), 984–988 (2020).
10. <https://uv-can.com/collections/far-uv-222nm-disinfection-components/products/helios-far-uv-222nm-excimer-lamp> (accessed July 05, 2025).
11. Blatchley III E. R., Brenner D. J., Claus H., Cowan T. E., Linden K. G., Liu Y., Ted Mao, Sung-Jin Park, Piper P. J., Simons R. M. and Sliney D. H., *Critical Reviews in Environmental Science and Technology* **53** (6), 733–753 (2022). doi: 10.1080/10643389.2022.2084315
12. Welch D., Buonanno M., Grilj V., Shuryak I., Crickmore C., Bigelow A. W., Randers-Pehrson G., Johnson G. W. and Brenner D. J., *Scientific Reports* **8** (1), 2752 (2018). doi: 10.1038/s41598-018-21058-w
13. Setlow J. The molecular basis of biological effects of ultraviolet radiation and photoreactivation. In *Current topics in radiation research*, M. E.; A. H., Eds. North Holland Publishing Company: Amsterdam, 1966. Vol. II. P. 195–248.
14. Buonanno M., Stanislauskas M., Ponnaiya B., Bigelow A. W., Randers-Pehrson G., Xu Y. and Brenner D. J., *PLoS ONE* **11** (6), e0138418 (2016). doi: 10.1371/journal
15. Narita K., Asano K., Morimoto Y., Igarashi T. and Nakane A., *PLoS ONE* **13** (7), e0201259 (2018). doi: 10.1371/journal.pone.0201259
16. Hessling M., Haag R., Sieber N. and Vatter P., *GMS Hyg Infect Control* **16**, Doc07 (2021). doi: 10.3205/dgkh000378
17. Narita K., Asano K., Naito K., Ohashi H., Sasaki M., Morimoto Y., Igarashi T. and Nakane A., *J. Hosp Infect.* **105** (3), 459–467 (2020). doi: 10.1016/j.jhin.2020.03.030
18. Ohashi H., Koi T. and Igarashi T., *Journal of Science and Technology in Lighting* **44**, 9–11 (2020). doi: 10.2150/jstl.IEIJ20A000006

19. Zwicker P., Schleusener J., Lohan S. B., Busch L., Sicher C., Einfeldt S., Kneissl M., Kuhl A. A., Keck C. M., Witzel C., Kramer A. and Meinke M. C., *Sci Rep.* **12** (1), 2587 (2022). doi: 10.1038/s41598-022-06397-z
20. Buonanno M., Welch D. and Brenner D. J., *Photochemistry and Photobiology* **97** (3), 517–523 (2021). doi: 10.1111/php.13383
21. Woods J. A., Evans A., Forbes P. D., Coates P. J., Gardner J., Valentine R. M. and Moseley H., *Photodermatology, Photoimmunology & Photomedicine* **31** (3), 159–166 (2015). doi: 10.1111/phpp.12156
22. Tavares R. S. N., Adamoski D., Girasole A. et al., *J. Photochem Photobiol B.* **243**, 112713 (2023). doi:10.1016/j.jphotobiol.2023.112713
23. Kaidzu S., Sugihara K., Sasaki M., Nishiaki A., Ohashi H., Igarashi T. and Tanito M., *Photochemistry and Photobiology* **97** (3), 505–516 (2021). doi: 10.1111/php.13419
24. Sugihara K., Kaidzu S., Sasaki M. et al., *Photochem Photobiol.* **99** (3), 967–974 (2023). doi: 10.1111/php.13710
25. Kousha O., O'Mahoney P., Hammond R., Wood K. and Eadie E., *Photochem Photobiol.* **100**, 137–145 (2024). doi: 10.1111/php.1380
26. Claus H., *Photochemistry and Photobiology* **97** (3), 471–476 (2021). doi: 10.1111/php.13391

About authors

Vasilyak Leonid Mikhailovich, Doctor of Physical and Mathematical Sciences, Senior Research Assistant, Joint Institute for High Temperatures of Russian Academy of Sciences (125412, Russia, Moscow, 13, Izhorskaya st., bldg. 2). E-mail: vasilyak@ihed.ras.ru SPIN code: 5623-5167, AuthorID: 19599, ORCID 0000-0001-6982-3038, Scopus 7004886755

Kudryavtsev Nikolay Nikolaevich, president, academician, Moscow Institute of Physics and Technology, (141701, Russia, Moscow region, Dolgoprudny, 9, Institutsky lane). AuthorID: 19586, Scopus 7006127196

Kostyuchenko Sergey Vladimirovich, Candidate of Physical and Mathematical Sciences, Deputy Director for Science, NPO "LIT", (141701, Russia, Moscow region, Dolgoprudny, 25, Likhachevsky driveway). E-mail: lit@lit-uv.ru AuthorID: 19597, ORCID 0009-0005-7450-8741

Sivin Denis Olegovich, Candidate of Technical Sciences, Head of the Laboratory NPO "LIT", (141701, Russia, Moscow region, Dolgoprudny, 25, Likhachevsky driveway). E-mail: light@lit-uv.ru AuthorID: 139704, ORCID 0000-0002-6341-6180, Scopus 8351574400

Timofeev Ivan Sergeevich, Candidate of Physical and Mathematical Sciences, Technical Director of the Equipment Engineering Department, NPO "LIT", (141701, Russia, Moscow region, Dolgoprudny, 25, Likhachevsky driveway). E-mail: timofeev@lit-uv.ru SPIN code: 6932-1594, AuthorID: 839789