TBPI ™ Soft Ionization Compared with Ultraviolet Germicidal Irradiation: Byproducts, Ozone, and Indoor Air Chemistry

Abstract

Ultraviolet germicidal irradiation, commonly called UVGI or UVC, is an established technology for inactivating microorganisms. It can be effective when properly designed, applied, and maintained. However, recent peer-reviewed research shows that germicidal ultraviolet light can also affect indoor air chemistry. Depending on wavelength, intensity, exposure time, ventilation, background VOCs, surface materials, and room conditions, UVC and far-UVC systems have been found to generate ozone, ultrafine particles, oxidized volatile organic compounds, and other secondary reaction products [1], [2], [3], [4], [5]. Targeted Bipolar Pulsed Ionization, or TBPI, takes a different approach. TBPI is designed as a soft ionization technology that delivers controlled positive and negative ions without exposing occupied spaces to germicidal ultraviolet radiation and without using high-energy photochemical or plasma chemistry to fragment air constituents. Because TBPI is does not photolyze oxygen, ozone, water vapor, surface films, or VOCs, it is better suited for occupied-space contaminant control when the design objective is improved air quality without ozone formation or UV-driven byproduct chemistry

1. Introduction

UVC systems and TBPI systems are both used to improve indoor environmental quality by reducing pathogens, but they work by very different mechanisms.

UVC germicidal systems use ultraviolet photons, commonly around 254 nm or 222 nm, to damage microorganisms. The germicidal effect occurs because UV photons can damage nucleic acids and other biological molecules, reducing the ability of bacteria, viruses, and fungi to reproduce or remain infectious. This makes UVC useful for air-stream disinfection, upper-room germicidal irradiation, surface disinfection, and coil irradiation.

TBPI does not rely on ultraviolet photon energy. TBPI is a soft ionization technology designed to generate controlled ion output and tune polarity toward target contaminant classes. Instead of using photon-driven chemistry to damage biological molecules or oxidize contaminants, TBPI uses charged species and electrostatic interactions to influence contaminants.

The safety distinction is important. UVC is a photochemical technology. It can interact not only with microbes but also with oxygen, ozone, VOCs, surface films, skin oils, cleaning residues, building materials, and other indoor compounds. Recent peer reviewed research has shown that these interactions create unintended indoor air chemistry, including ozone, VOC changes, and ultrafine particle formation [1], [2], [3], [4], [5].

TBPI is designed to avoid this photochemical pathway. It does not irradiate occupied spaces with germicidal UV energy, does not rely on photolysis, and does not oxidize VOCs. Therefore, when properly designed and tested, TBPI can offer contaminant control without the same ozone and byproduct concerns associated with UVC-driven indoor chemistry.

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2. How UVC Works

UVC germicidal systems use short-wavelength ultraviolet radiation to damage microorganisms. Traditional low-pressure mercury lamps often emit near 254 nm. Newer far-UVC systems commonly emit near 222 nm. Both wavelengths can be germicidal, although they differ in penetration depth, photochemistry, ozone-generation potential, and exposure considerations.

UVC is effective because the photons carry enough energy to alter chemical bonds in biological molecules. That same property creates the core air-chemistry concern. If UVC photons can break or alter biological molecules, they can also interact with non-biological molecules in indoor air or on indoor surfaces.

Recent research has shown that UVC exposure can affect:

- oxygen;
- ozone;
- water vapor;
- VOCs;
- skin oils;
- cleaning residues;
- surface films;
- indoor particles;
- building material emissions.

A 2023 study of a commercial high-intensity UVC disinfection device found that UVC operation caused dramatic increases in particle number concentration and increases in many monitored gas-phase species [1]. Other studies of 222 nm germicidal UV have shown ozone generation in both chamber and real-world settings [2], [3]. A 2024 study specifically reported ozone formation, ultrafine particle formation, and changes in VOC levels from 222 nm germicidal UV lamps in indoor office spaces [4].

This does not mean UVC has no place. It means UVC must be treated as an active photochemical technology, not merely a passive disinfection tool. When specifying UVC or installing UVC, the end user must be made aware that these byproducts will worsen the IAQ and consider if the germicidal benefit outweighs the reduction in IAQ.

3. UVC and Ozone Formation

Ozone is one of the most important byproduct concerns for germicidal UV systems.

At 222 nm, photons are energetic enough to photolyze oxygen-containing species and initiate ozone formation pathways. Link et al. reported that 222 nm germicidal UV light can produce ozone in air and noted that ozone is undesirable indoors because of both health impacts and its ability to degrade indoor air quality through oxidation chemistry [2]. Peng et al. also reported significant ozone production from 222 nm germicidal UV lamps and found ozone formation across multiple commercial lamps [3].

Ozone matters for two reasons. First, ozone itself is a regulated respiratory irritant. It can irritate the lungs and airways, especially in sensitive populations. Second, ozone is chemically reactive. Once formed indoors, ozone can react with VOCs from cleaning products, fragrances, human emissions, building materials, and furnishings. These reactions can produce aldehydes, organic acids, oxidized VOCs, and secondary organic aerosol. Indoor chemistry reviews have long recognized ozone-initiated chemistry as an important source of secondary indoor pollutants [6].

TBPI avoids this specific risk pathway because it is not based on oxygen photolysis. TBPI does not use 222 nm or 254 nm photons to irradiate indoor air. Its purpose is controlled ion delivery rather than UV-driven photochemical disinfection. As a result, TBPI does not create the same ozone-generation mechanism associated with far-UVC lamps.

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4. UVC, VOCs, and Ultrafine Particles

Recent peer-reviewed papers have raised a second major concern: UVC can generate or alter VOCs and ultrafine particles.

Graeffe et al. studied a commercial high-intensity UVC device and reported increases in particle number concentrations and increases in many gas-phase species during UVC operation [1]. This is important because it shows that UVC can do more than inactivate microorganisms. It can also trigger chemical and particle formation processes in indoor air.

Sørensen et al. studied 222 nm germicidal UV lamps in indoor office spaces and reported formation of ozone, ultrafine particles, and alterations in VOC levels [4]. This is directly relevant to occupied-space applications because 222 nm far-UVC is often promoted as suitable for use in occupied rooms.

Carter et al. modeled the impact of UVC light on indoor air chemistry and found that germicidal UV can alter indoor oxidant chemistry, including chemical pathways involving ozone, hydroxyl radicals, and VOC oxidation products [5]. This supports the broader point that germicidal UV is not chemically neutral in indoor environments.

The formation of ultrafine particles is especially important. Ultrafine particles are small enough to penetrate deeply into the respiratory system. Their health impacts depend on concentration, chemistry, exposure duration, and particle composition, but their formation should not be ignored in air-cleaning evaluations.

TBPI does not rely on photolysis of VOCs or surface films. It does not shine high-energy UV photons onto indoor air, skin oils, surfaces, or cleaning residues. Therefore, TBPI avoids the UV-driven pathway that recent studies have associated with VOC changes and ultrafine particle formation.

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5. UVC and Surface Chemistry

UVC systems can affect more than the air stream. UV photons can strike surfaces and surface films. In real indoor environments, surfaces are not chemically clean. They contain skin oils, cleaning chemicals, plasticizers, fragrances, cooking residues, dust, and adsorbed VOCs.

When UVC irradiates these materials, it can alter surface chemistry and release new gas-phase compounds. This issue is especially relevant for high-intensity mobile UVC disinfection systems, upper-room UVC systems with poor shielding, and far-UVC systems used continuously in occupied spaces.

Indoor chemistry is already complex without adding UV. Weschler and Carslaw described indoor environments as chemically active systems involving ozone, oxidants, surfaces, human emissions, cleaning products, and ventilation [6]. UVC can add a new energy source into that chemistry.

TBPI avoids this concern because it does not irradiate surfaces. There is no UV beam, no lamp exposure field, no surface photolysis, and no UV degradation of materials. That makes TBPI a fundamentally different approach from UVC.

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6. Direct Exposure and Maintenance Differences

UVC also has direct safety and maintenance considerations that TBPI does not share.

Traditional 254 nm UVC can damage skin and eyes if people are exposed directly. This is why 254 nm systems are usually installed inside air handlers, inside ductwork, in enclosed chambers, or in upper-room configurations with careful shielding and commissioning. When installed inside air handlers or ductwork, electrical safety interlocks are highly recommended to de-energize the UVC when the access compartments are opened.

Far-UVC at 222 nm has been promoted as safer for occupied spaces because it penetrates less deeply into skin and eye tissue. However, the indoor chemistry literature shows that even when direct tissue exposure risk is reduced, air-chemistry concerns can remain [2], [3], [4], [5].

UVC systems also require maintenance. Lamp output declines over time, lamps can foul, reflectors can degrade, and lamp replacement is required. Traditional mercury lamps also raise handling and disposal concerns. LEDs can reduce some of these concerns, but they still require thermal management, optical design, power electronics, and verification of delivered dose. LED UVC lamps have a limited life with manufacturers reporting up to 5 years of service.

TBPI does not require UV lamps, UV shielding, lamp-dose calculations, mercury lamp disposal, or UV exposure controls. Its key design and verification requirements are different: ion output, polarity control, ion delivery and electrical safety.

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7. TBPI as a Soft Ionization Alternative

TBPI is best described as a soft ionization technology. It is designed to control ion polarity and timing rather than expose air or surfaces to germicidal ultraviolet radiation.

The key TBPI differences are:

Controlled polarity

TBPI can bias ion output positive or negative depending on the contaminant being targeted.

Pulsed operation

TBPI can separate positive and negative ion generation in time, reducing immediate recombination and improving ion availability.

No UV photon exposure

TBPI does not use 222 nm or 254 nm radiation, so it avoids UV-driven photolysis of oxygen, ozone, VOCs, surface films, and cleaning residues.

No intended VOC oxidation

TBPI is not designed to oxidize VOCs or chemically decompose air contaminants. This prevents the forming of partial oxidation byproducts.

Ozone-generation mechanism from UV photolysis

Because TBPI does not use far-UVC photons, it avoids the oxygen-photolysis pathway associated with ozone production from 222 nm germicidal lamps [2], [3].

Occupied-space compatibility

TBPI is better aligned with occupied-space use because it avoids direct UVC exposure hazards and the UV-driven indoor chemistry pathways now being documented in the literature [1], [2], [3], [4], [5].

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8. Comparative Summary

Issue	UVC / UVGI	TBPI Soft Ionization
Primary mechanism	UV photon damage to microorganisms	Controlled ion generation and polarity targeting
Typical wavelengths	254 nm or 222 nm	No UV wavelength
Direct exposure concern	Skin and eye risk, especially 254 nm	No UV exposure
Ozone concern	222 nm can produce ozone [2], [3]	No ozone per UL 2998
VOC chemistry	Can alter VOCs and oxidant chemistry [1], [4], [5]	Does not oxidize or fragment VOCs
Ultrafine particle concern	Reported in recent studies [1], [4]	No UV-driven particle formation pathway. Ultrafine particle reduction
Surface chemistry	Can photolyze surface films and residues	No surface photolysis
Maintenance	Lamp aging, fouling, replacement, dose verification	Ion output and target verification. No replacement parts
Best application fit	Controlled disinfection applications with shielding, ventilation, and dose control	Coil cleaning and occupied-space contaminant control without UV byproduct chemistry

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9. Conclusion

UVC and TBPI are fundamentally different technologies.

UVC can inactivate microorganisms, but the same UV photon energy that damages biological molecules can also interact with oxygen, ozone, VOCs, surface films, and indoor materials. Recent peer-reviewed studies show that UVC and far-UVC systems can generate ozone, increase ultrafine particles, alter VOC levels, and initiate indoor air chemistry [1], [2], [3], [4], [5].

TBPI is a soft ionization technology. It does not use germicidal ultraviolet light, does not irradiate occupied spaces, does not photolyze oxygen, and does not oxidize VOCs. Instead, TBPI uses controlled ion polarity and timing to target contaminants through charge-based interactions.

The safety advantage of TBPI is that it avoids the UV-driven mechanisms now associated with ozone formation, VOC byproducts, ultrafine particles, and indoor photochemistry. For occupied indoor environments, that distinction matters. UVC can be effective when engineered and controlled correctly, but TBPI offers a cleaner and more suitable pathway when the goal is continuous contaminant control without ultraviolet exposure or photochemical byproducts. In addition, TBPI does not require replacement parts and uses approximately 1/10 of the energy required by UVC.

References

[1] Graeffe, F., et al. “Unwanted Indoor Air Quality Effects from Using Ultraviolet C Lamps for Disinfection.” *Environmental Science & Technology Letters*, 2023. The study reported that operation of a commercial high-intensity UVC device caused large increases in particle number concentrations and increases in many monitored gas-phase species.

[2] Link, M. F., et al. “Ozone Generation from a Germicidal Ultraviolet Lamp with Peak Emission at 222 nm.” *Environmental Science & Technology Letters*, 2023. The authors reported that 222 nm germicidal UV light can produce ozone in air and noted ozone’s health and indoor chemistry concerns.

[3] Peng, Z., et al. “Significant Production of Ozone from Germicidal UV Lights at 222 nm.” *Environmental Science & Technology Letters*, 2023. The authors observed ozone formation from multiple 222 nm lamps and reported ozone generation in controlled and real-world settings.

[4] Sørensen, S. B., et al. “Influence of Germicidal UV (222 nm) Lamps on Ozone, Ultrafine Particles, and Volatile Organic Compounds in Indoor Office Spaces.” *Environmental Science & Technology*, 2024. The study reported formation of ozone and ultrafine particles and changes in VOC levels from 222 nm germicidal UV lamps.

[5] Carter, T. J., et al. “The Impact of UVC Light on Indoor Air Chemistry: A Modeling Study.” *Environmental Science & Technology*, 2025. The modeling study evaluated how 222 nm and 254 nm germicidal UV can affect indoor gas-phase chemistry.

[6] Weschler, C. J., and Carslaw, N. “Indoor Chemistry.” *Environmental Science & Technology*, 2018. This review describes the complexity of indoor chemical reactions involving ozone, oxidants, VOCs, surfaces, and ventilation.