



UV-C Disinfection in the Environment of Pathogen Transmission

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Abstract

Coronavirus disease 2019 (COVID-19) is a respiratory infection caused by SAR-COV-2 (COVID-19 virus). COVID-19 typically rapidly spread from one person to another via respiratory droplets ($>5\text{-}10\text{ }\mu\text{m}$ in diameter) during coughing and sneezing or touch. Thus, environmental surfaces should be frequently cleaned with water, detergent, and followed by application of disinfection as chemical disinfectants and physical disinfection. Ultraviolet germicidal irradiation (UVGI) is the use of ultraviolet energy to inactivate viral, bacterial, and fungal species because the UVC directly damages deoxyribonucleic acid (DNA), Ribonucleic acid (RNA), and also prevent the bacterium from being viable. The most effective wavelength is in 245 -285 nm. Conventional ultraviolet disinfection consists of a mercury amalgam, which is a hazardous material to the environment. In addition, excessive exposure causes sunburn skin, skin cancer and damage to the corneas of the eyes. Therefore, the risk management such as enclosure cabinets, indicator warning sign light, and personal protection equipment (PPE) should be considered.

Introduction

On 31 December 2019, Wuhan Municipality in Hubei Province, People's Republic of China reported a cluster of pneumonia cases with unknown etiology. On 30 January 2020, more than 9,700 confirmed cases in China and 106 confirmed cases in 19 other countries, the World Health Organization (WHO) Director General declared the outbreak a public health emergency of international concern (PHEIC). On 11 February, WHO named the disease, COVID-19, short for "coronavirus disease 2019." On the same day, the International Committee on Taxonomy of Viruses (ICTV) announced "severe acute respiratory syndrome coronavirus 2

(SARS-CoV-2)" as the name of the new virus which causes COVID-19 (Pan American Health Organization [PAHO] & World Health Organization [WHO], 2020; Ragan et al., 2020). Coronavirus disease 2019 (COVID-19) is a respiratory infection caused by SAR-COV-2 (COVID-19 virus). Common symptoms include fever, cough, sneezing, sore throat, breathlessness, fatigue, pneumonia, acute respiratory distress syndrome (ARDS) (Hafeez et al., 2020) and multi organ dysfunction (Singhal, 2020; Hafeez et al., 2020; Occupational Safety and Health Administration [OSHA], 2020). Some symptoms of SARS-CoV-2 induced COVID-19 are a bit similar to influenza and seasonal allergies (pollen allergies) therefore suspected patients may also exhibit

temperature which can be detected by thermo-scanners, as well as be detected with an accurate and rapid diagnostic kit of SARS-CoV-2 (Shereen et al., 2020). Time from exposure and symptom onset is generally between two and 14 days, with an average of five days. The elderly and people with underlying diseases are susceptible to infection and prone to serious outcomes (Guo et al., 2020).

COVID-19 transmission

SARS-CoV-2 is an enveloped virus with an outer lipid envelope as shown in Fig.1 (Hafeez et al., 2020), which makes it more susceptible to disinfectants compared to nonenveloped viruses. The virus that causes COVID-19 is typically rapidly spread from one person to another via respiratory droplets ($>5\text{-}10\text{ }\mu\text{m}$ in diameter) during coughing and sneezing (WHO, 2020a) or close contact (Salem et al., 2020). Droplet transmission of the COVID-19 virus can occur by direct contact with infected people and indirect contact with surfaces. Environmental infection control of surfaces and limiting person-to-person contact are important steps (Jones, 2020). Recommended preventive measures include washing your hands with soap, covering the mouth when coughing, and monitoring and self-isolation for fourteen days for people who suspect they are infected (Hafeez et al., 2020). The survival time of the coronavirus 2019-nCoV were differed at different environment as shown in Table 1 (Zhou, 2020). Regular housekeeping practices include routine cleaning of surfaces, equipment, and other elements of the work environment to reduce exposure to hazards (OSHA, 2020). In addition, healthy indoor air quality (IAQ) should be interpreted by cleaning and disinfection of environmental surfaces (Kamaruzzaman & Sabrani, 2011).

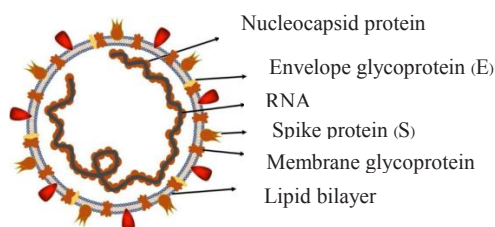


Fig. 1 A structure of SARS-CoV-2
Source: Hafeez et al. (2020)

Table 1 Survival time of the coronavirus 2019-nCoV on different surfaces and specific temperatures

Different environments	Temperature	Survival time
Air	50 – 59 F	4 hours
	77 F	2 – 3 minutes
Droplets	<77 F	24 hours
Nasal mucus	132.8 F	30 minutes
Liquid	167 F	15 minutes
Hands	68 – 86 F	< 5 minutes
Non-woven fabric	50-59 F	< 8 hours
Wood	50 – 59 F	48 hours
Stainless steel	50 – 59 F	24 hours
75 % alcohol	Any temperature	< 5 minutes
Bleach	Any temperature	< 5 minutes

Source: Zhou (2020)

Environment disinfection

Cleaning is the removal of gross contamination, organic material, and debris from the premises or respective structures, via mechanical means like sweeping (dry cleaning), mechanical action (brushing or scrubbing) and/or the use of water and soap or detergent (wet cleaning). Its goal is to minimize dirt, debris, and organic material such as blood, secretions and excretions but does not kill microorganisms (Foreign Animal Disease Preparedness and Response Plan [FAD PReP], 2018; WHO, 2020a; WHO, 2020b). Disinfection is the methods used on surfaces to destroy or eliminate a specific species of infectious microorganism through physical (e.g., heat) or chemical (e.g., disinfectant) means (FAD PReP, 2018). It is the primary mechanism for the inactivation of pathogenic organisms to prevent the spread of diseases to the environment (Environmental Protection Agency [EPA], 1999).

1. Chemical disinfection

Environmental surfaces should be frequently cleaned with water, detergent, and disinfectant, respectively. Chemical disinfectants inactivate a wide variety of microorganisms. In indoor spaces, routine application of disinfectants to material surfaces via spraying or fogging (also known as fumigation or misting) is not recommended (WHO, 2020a). Spraying individuals with disinfectants (such as in a tunnel, cabinet, or chamber) is not recommended under any circumstances owing to health effects on eyes, respiratory system, skin irritation, and gastrointestinal (WHO, 2020a; WHO, 2020b). The concentration and contact time of disinfectant are also critical for effective surface disinfection (WHO, 2020b) as shown in Table 2 (Rutala et al., 2019; Ogilvie et al., 2021). The most commonly used alcohol-based disinfectants are

ethyl alcohol (ethanol 70-90%) and isopropyl alcohol (isopropanol). The oxidizing agents peroxide-based disinfectants are hydrogen peroxide, which solutions of 5-20% are considered for bactericidal, enveloped virus, fungicidal, and sporicidal (FAD PRoP et al., 2014). The chlorine-based product (e.g., hypochlorite) at 0.1% (1000 ppm) was recommended for general environmental disinfection (WHO, 2020a). Chlorhexidine (also known as chlorhexidine gluconate) also effectively inactivates the virus (Zhou, 2020). Owing to the length of time that COVID-19 virus can survive on inanimate surfaces varies depending on factors such as the amount of contaminated body fluid (e.g. respiratory droplets) and environmental temperature as well as humidity; routine environmental cleaning on touched surfaces e.g. door handles, tabletops, light switches by using detergent solution and disinfectant solution can reduce environmental contamination (WHO, 2020c).

Table 2 Concentration and contact time of different chemical disinfectants for surface disinfection

Chemical disinfectants	Concentration required to destroy	Contact time
Alcohol	Ethyl alcohol and isopropyl alcohol 60%–90% solutions in water (volume/volume)	10 seconds
Chlorine compounds	5.25%–6.15% Sodium hypochlorite	1 minute
Formaldehyde	Formalin, which is 37% formaldehyde by weight	2 minutes
Glutaraldehyde	≥2% Aqueous solutions of glutaraldehyde, buffered to pH 7.5–8.5 with sodium bicarbonate	<2 minutes
Hydrogen peroxide	0.5% Hydrogen peroxide	1 minute
Iodophors	Iodine 75–150 ppm	seconds to minutes
Ortho-phthalaldehyde (OPA)	0.55% 1,2-benzenedicarboxaldehyde (OPA).	5 minutes
Peracetic acid or peroxyacetic	1,500–2,250 ppm	15 minutes
Peracetic acid and hydrogen peroxide	0.08% Peracetic acid plus 1.0% hydrogen peroxide, 0.23% Peracetic acid plus 7.35% hydrogen peroxide	20 minutes
Benzalkonium chlorides	0.2% w/w in water	15 seconds

2. Physical disinfection

Physical disinfection can be used by heat and ultraviolet radiation. Heat is the thermal inactivation of infectious agents. Heat destroys microorganisms by causing deoxyribonucleic acid (DNA) disruption, protein denaturation, oxidative damage, and loss of membrane integrity. The time required is inversely related to the temperature and directly related to the number of

microorganisms. Heat can be applied under moist (e.g., autoclave, steam) or dry (e.g., incineration, baking) conditions. Moist heat can be effectively applied through steam under pressure when dealing with thermally resistant bacterial spores. Dry heat applications can be useful for the disinfection of heat-resistant materials, such as glass or metals. Moist heat applications are generally more effective and require less time than dry heat. In addition, the coronavirus is sensitive to sustained heat at 132.8°F for 30 minutes (Zhou, 2020).

The Ultraviolet (UV) in sunlight is in the wavelength 300-400 nm and is not very effective to inactivate microorganisms. The most effective biocidal wavelength is in 245-285 nm. Inactivation of microorganisms results from destruction of nucleic acid through induction of thymine dimers. Bacterial spores will require 10 times the exposure time as the vegetative forms of the organisms. Its germicidal effectiveness is influenced by wavelength; UV intensity, type of suspension; and type of microorganism (Rutala et al., 2019). In addition, UV in 245–285 nm may be useful for the control of SAR-COV-2 airborne pathogens in enclosed areas because the coronavirus is sensitive to ultraviolet rays (Zhou, 2020).

Ultraviolet disinfection

UV emitted from the region of the solar spectrum between visible light (400-750 nm) and x-rays. The UV spectrum is commonly divided into UVA (wavelength of 400 nm to 315 nm), UVB (315 nm to 280 nm), UVC (280 nm to 200 nm) (Martin et al., 2008), and vacuum UV (VUV) at 100-200 nm (Vatansever et al., 2013). The atmospheric ozone layer in the stratosphere, about 10-50 kilometers above the Earth's surface absorbs and scatters UV light (UVB and UVC) from the Sun (Carlowicz, 2013). The absorption of radiation by atmospheric gases and scattering by atmospheric aerosols, and clouds, as well as the earth's surface prevent all UVC radiation from reaching the troposphere and the earth's surface (Kerr, 2005). The earth absorbs much radiation from the Sun to warm the atmosphere, the land, and the oceans.

UVA and UVB cause sun burning, photo aging skin (Vatansever et al., 2013), and also damaged eyes (Solomon, 2008). Prolonged human exposure to solar UV radiation may result in acute and chronic health effects on the skin, eye and immune system (WHO et al, 2002). UV radiation emitted by sunbeds, is a complete carcinogen, as it acts both as an initiator and a promoter.

An initiator causes a genetic mutation or epigenetic changes while a promoter causes rapid cell growth. There is no threshold level of UV-fluence and UV-dose for the induction of skin cancer. The beneficial effects of sunbed use, such as generation of vitamin D (Orazio et al., 2013), are outweighed by the adverse effects. There is no need to use sunbeds to induce vitamin D production because alternative sources of vitamin D are readily available. Therefore, there is no safe limit for exposure to UV radiation from sunbeds (Scientific Committee on Health, Environmental and Emerging Risks [SCHEER], 2017). In addition, solar UV radiation penetrates to ecological significant depths in aquatic systems and can affect in the food web (Häder et al., 2007). Exposure to solar UV radiation can reduce productivity of aquatic organisms. Corals live in an environment characterized by high ambient levels of UVC radiation resulting in the death of gastrodermal cells and injured as evidenced by pale coloration (Basti et al., 2009).

UVC has also been an important tool for wastewater treatment (Vatansever et al., 2013). The Photocatalytic of UVC radiation and the adsorption with nanoclay can remove an anionic dye (RR120) from wastewater (Siahpoosh & Soleimani, 2017). The application of UVC radiation caused COD removal in the Sulphate Radical-Based Advanced Oxidation Processes (SR-AOP) of winery wastewater treatment (Amor et al., 2019). The harmful anionic surfactants in aqueous ecosystems can be degraded by using H_2O_2 /UVC system (Rios et al., 2017). The UVC/ H_2O_2 , VUV and VUV/ H_2O_2 processes removal total organic carbon (TOC) from the Biologically-treated hospital wastewater (BHW) (Moussari et al., 2019). The combined ozone/UV treatments were able to achieve zero *E. coli* and *A. niger* count for cloudy and turbid medium, like flour slurry (Sangadkit et al., 2020).

UVC has also been an important tool for food processing industry (Vatansever et al., 2013). It over 60 seconds decreased the inoculated *Staphylococcus aureus* population in precooked shredded bullfrog meat (Silva et al., 2015). It reduced the *Salmonella* spp. in caiman meat (Canto et al., 2019). Its radiation improved the safety of fish fillets from fresh water and marine sources (Ahmed & Amin, 2019). The combination of its irradiation and lactic acid bacteria (LAB) inhibited the growth of *Salmonella enteritidis* during storage of fresh-cut apples (Chen et al., 2017). It treated strawberries inhibit microbial loads and delay ripening process of fruit products (Idzwana et al., 2019). Its

treatment reduced the natural microflora growth of fresh rocket leaves (Rivera-Gutiérrez et al., 2015). The combination of it and aerosolized 2% malic acid can inhibit the growth of foodborne pathogens on fresh-cut lettuce (Seong et al., 2016). Its radiation removed larvae (Adams et al., 2018) and increased mortality of adult insects (Poushand et al., 2017).

Ultraviolet germicidal irradiation (UVGI) has been used in disinfection infectious agents. UVGI emits nonionizing electromagnetic radiation with UVC wavelength of 254 nm inactivate viral, bacterial, and fungal species (Martin et al., 2008) through the damage to DNA and ribonucleic acid (RNA). The UVC spectrum has been produced by mercury vapor arc lamps enclosed in a quartz tube (Martin et al., 2008; Vatansever et al., 2013). The dosage of UVC was proportional to distance from the UV device, exposure time, the amount of energy in watts per unit surface area (WHO, 2020b). Dose and is expressed in microwatt seconds per centimeter squared ($\mu Wsec/cm^2$). Divide by 1000 to express the dose in the preferred notation millijoule per centimeter squared (mJ/cm^2) (Renzel, 2016). Furthermore, humic materials can shield embedded bacteria (EPA, 1999). Thus, UV-disinfection reactors should be designed to deliver the highest amount of radiation at direct radiation zone (Artichowicz et al., 2020). UVGI can reduce the concentrations of airborne bacteria in the indoor environment (Kujundzic et al., 2006; Makarapong et al., 2020; Szeto et al., 2020). The combination of UVC mainly 254 nm and VUV at 185 nm can inactivate airborne human pathogens for bacteria (Szeto et al., 2020). In addition, airborne bacteria were reduced between 79 and 91% while most surfaces also showed reductions in bacteria from 48 to 69% (Lee, 2017). The capacity of a portable ultraviolet-C equipment (UV Sanitizer Corvent® -UVSC-) in disinfection Pathogens: *Acinetobacter baumannii*, *Bacillus subtilis*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Staphylococcus aureus* and *Candida albicans* was achieved with 99.99% at 120 seconds of exposure time (Guridi et al., 2019). UVGI was disinfection of air in health care facilities to meet indoor air quality (IAQ) requirements (Memarzadeh et al., 2010; Warren et al., 2020). The advantage of UVC using in environmental disinfection were shown in Table 3 (Ontario Agency for Health Protection and Promotion, 2018; Elguijja et al., 2020).

Table 3 Advantage and disadvantage of UVC using in environmental disinfection

No.	Advantage	Disadvantage
1.	Broad-spectrum activity against pathogens involved in healthcare-associated infections	-
2.	Can be used for disinfecting both environmental surface as well as medical devices	Cannot be used as stand-alone disinfection
3.	Rapid contact time, for example, 15 minutes for vegetative bacteria	-
4.	Has a sporicidal activity after longer exposure for up to 50 minutes	-
5.	Does not require closing the HVAC (Heating-Ventilation-Air Conditioning) system, nor sealing the room	The room must be vacated for decontamination
6.	Eco-friendly, with no residue	-
7.	Low operating costs	High capital costs

Conventional ultraviolet (UV) disinfection consists of a mercury amalgam encapsulated within a quartz sleeve (Simons et al., 2018). Due to the Minamata conventional of The United Nations Environment Programme (UNEP) relating to storage of Mercury compounds (Article 10) and mercury waste in Basel Convention on the Control of Transboundary Movements of Hazardous Wastes (Article 11), the mercury content of conventional was limited in order to ensure human

and environmental health (Kim & Kang, 2018). Because of Mercury is a very toxic substance on both human health and the environment. Inhalation of mercury vapour can cause harmful effects on the nervous as insomnia, memory loss, digestive and immune systems. With the environment, mercury vapour can bio-accumulates and converted to methyl mercury by microorganisms. Therefore, the Ultraviolet Light-emitting diode (UVC LED), which does not contain mercury, and Xenon lamps have gained prominence. In addition, arrays of LED and pulsed xenon-based ultraviolet light (PX-UVC) can be efficient inactivation (Mori et al., 2007; Simons et al., 2018; Kim & Kang, 2018; Xiao et al., 2018; Casini et al., 2019). However, the UV-C Light-emitting diode (LED) at a wavelength of 240 nm produces ozone, which is a strong oxidant and toxic air pollutant (Vatansever et al., 2013; Global Lighting Association, 2020).

UVC Disinfection of COVID-19 virus

Owing to SARS-CoV-2 as the virus which causes COVID-19, the previous UVC methodology and results of other researchers concentrating on virus were concluded as shown in Table 4.

Table 4 Example of UVC exposure on virus

Description of virus	Methodology (wavelength, fluence, duration of exposure)	Results	References
H1N1 on Petri dishes at distance of 5 cm at 25°C	VUV 185 nm, 21 mW/cm ² , 0 to 15 minutes	Inactivate by 2.2-log ₁₀ within 5 minutes and more than 4-log ₁₀ within 20 minutes	Szeto et al. 2020
H3N2 on Petri dishes	VUV 185 nm, 21 mW/cm ² , 0 to 15 minutes	Inactivate by 3.0-log ₁₀ within 5 minutes and more than 4-log ₁₀ within 20 minutes	Szeto et al. 2020
SARS-CoV-2	UVC 254 nm, 80 J/mL, 52 minutes	Reduction $\geq 4.79 \pm 0.15 \log_{10}$ in plasma and $3.30 \pm 0.26 \log_{10}$ in whole blood	Ragan et al. 2020
SARS-CoV in plasma	UVC 254 nm, 30 J/cm ²	Inactivate by $\geq 3.1 \log_{10}$	Eickmann et al. 2020
Crimean-Congo haemorrhagic fever virus (CCHFV) in plasma	UVC 254 nm, 30 J/cm ²	Inactivate by $\geq 3.2 \log_{10}$	Eickmann et al. 2020
Nipah virus (NiV) in plasma	UVC 254 nm, 30 J/cm ²	Inactivate by $\geq 2.7 \log_{10}$	Eickmann et al. 2020
SARS-CoV-2 on Petri dishes	Deep ultraviolet light-emitting diode (DUV-LED) 280 \pm 5 nm, 225 mW/cm ² , 60 seconds	Inactivate $> 3.3 \log_{10}$	Inagaki et al. 2020
MS2, Q β , and ϕ X174 viruses in a chamber-type air disinfection system	UVC LED 254 nm, 45 mJ/cm ² , 10 minutes	Inactivate 5-log ₁₀	Kim & Kang, 2018
Ebola on Petri dishes	UVC 254 nm, 4-17 J/m ² , 0 to 30 seconds	Survival 3%–4%	Sagripanti & Lytle, 2011
Lassa on Petri dishes	UVC 254 nm, 4-17 J/m ² , 0 to 30 seconds	Survival 9%–10%	Sagripanti & Lytle, 2011
Respiratory Adenovirus	UVC 254 nm, 2608 W s/cm ² , 30 minutes	Survival 32.9%	Walker & Ko, 2007
Coronavirus.	UVC 254 nm, 599 W s/cm ² , 30 minutes	Survival 12.2%	Walker & Ko, 2007
SARS-CoV	UVC 254 nm, 4016 μ W/cm ² (where μ W = 10 ⁻⁶ J/s), 15 minutes	Inactivation 400-fold within 6 minutes	Darnell et al. 2004
SARS coronavirus strain CoV-p9 at distance of 80 cm	260 nm, > 90 W/cm ² , 15 to 150 minutes	CPE (cytopathic effect) dropped from +++CPE (51–75% cells) to +CPE (less than 25% cells) after 15 minutes	Duan et al. 2003

UVC technology is an important component of eliminating viral infections in environment (Paria et al., 2018) and also blood-borne pathogens (Ragan et al., 2020). The robotic UVC radiation was effective in inactivating 99.9% of *Pseudomonas aeruginosa*, which is more tolerate to UVC than the coronaviruses, on various surfaces including glass, plastic and stainless-steel within 10 minutes at the distance of 3 meters from the device (Vorapaluk et al, 2020). In addition, UVC 254-nanometer light robots of The San Antonio-based company Xenex Disinfection Services, which the robot named KENNEDY could eliminate corona virus 99.999% after two minutes of exposure at one-meter distance (Kalyani et al., 2020). Increasingly placed on the market with a greater range of UVC applications comes a greater risk of accidental exposure (Global Lighting Association, 2020). Excessive exposure causes sunburn skin, skin cancer and damage cornea of eyes. Risk management were engineering controls such as enclosure cabinets, screened area and administrative controls such as indicator warning sign light elimination of reflected UV from shiny surfaces, personal protection equipment e.g. latex gloves and eye protection. A UV-C warning symbol according IEC 61549-310-1 (Fig. 2), should be black on the yellow background with wording “Warning UV-C emitted from this product. Avoid eye and skin exposure to unshielded product. Follow installation instruction and user manual” (Global Lighting Association, 2020). In addition, humans and animals should not be exposed to high levels of UV light due to the potential for damage to the skin or eyes (FAD PreP

et al., 2014). Notably, these technologies developed for use in health-care settings are used during terminal cleaning (cleaning a room after a patient has been discharged or transferred), when rooms are unoccupied for the safety of staff and patients (WHO, 2020b).



Fig.2 Warning sign light

Moreover, the environmental measures proposed according to the probability level of COVID-19 virus infection spreading and workplace risk level were shown in Table 5 (Cirrincione et al., 2020). It aims at limiting the survival of the virus in key environments of non-healthcare facilities such as schools, institutions, offices, daycare centers, businesses, and community centers that do not house persons overnight. Extraordinary cleaning and disinfection procedures must be adopted using the appropriate disinfectants in the very airy confined spaces, personal protection equipment (PPE) as well as proper disposal of regulated waste (Department of Public Health, 2020).

Conclusion

COVID-19 typically rapidly spread from one person to another via respiratory droplets (>5-10 µm in diameter). Thus, environmental surfaces should be frequently cleaned with water, detergent, and followed

Table 5 Environmental measures proposed according to the workplace risk level

Risk level.	Probability level of infection spreading	Environmental measures
Low	<ul style="list-style-type: none"> Located in areas where there are no reported cases of disease contamination in the entire province With a maximum of 10 employees With mainly carry out office activities with a limited flow of customers 	<ul style="list-style-type: none"> Take extraordinary cleaning and sanitization Considering a density of 1 person every 10 square meters Keep a distance of 2 m between 2 or more people
Medium	<ul style="list-style-type: none"> Located in areas where there are reported cases of disease contamination in the province With a maximum number of 50 employees With mainly carry out commercial activities; Which expose employees to sporadic contact with customers 	<ul style="list-style-type: none"> All measures indicated for the previous level controls Indoor temperature >20 °C, indoor humidity >60% Preparation of special bins for the collection of contaminated materials
High	<ul style="list-style-type: none"> Located in areas in which in the neighboring cities or in the same city of the workplace, there are clear cases of disease contamination With a maximum number of over 50 employees With carry out front-office activities in continuous contact with customers 	<ul style="list-style-type: none"> All measures indicated for the previous level Prepare a suitable room for the isolation of any suspicious cases
Very high	<ul style="list-style-type: none"> Very-high-exposure-risk jobs include healthcare workers such as doctors, nurses, dentists, paramedics, emergency medical technicians 	<ul style="list-style-type: none"> All measures indicated for the previous level Ensure appropriate air-handling systems Negative pressure compared to the atmospheric one Sanitization through the use of physical means such as ultraviolet irradiation (UV)

by application of disinfection as chemical disinfectants and physical disinfection. UVGI in the wavelength of 245–285 nm directly damages deoxyribonucleic acid, ribonucleic acid, and also prevent the bacterium from being viable. However, its risk is mercury amalgam, which is a hazardous material. In addition, excessive exposure causes sunburn skin, skin cancer and damage to the corneas of the eyes.

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