End TB Transmission Initiative

MAINTENANCE OF UPPER-ROOM GERMICIDAL ULTRAVIOLET (GUV) AIR DISINFECTION SYSTEMS FOR TB TRANSMISSION CONTROL

USAID FROM THE AMERICAN PEOPLE

Partner of the Stop TB Partnership

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ACKNOWLEDGEMENTS

We would like to thank the reviewers for their comments and inputs to this first edition of *the Maintenance of Upper Room Germicidal Ultraviolet (GUV) Air Disinfection Systems for TB Transmission Control*.

This report was made possible through the support of Stop TB Partnership's End TB Transmission Initiative (ETTi) Working Group provided by the United States Agency for International Development (USAID), under the terms of cooperative agreement number STBP/USAID/GSA/WG/92954/2017-05.

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Cover Photo:

Engineer installing upper-room germicidal UV (GUV) fixture in Operating Theater, Mumbai, India. Photo: Richard L. Vincent

http://www.stoptb.org/wg/ett/

First Printing: September 1, 2017

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Reducing Risk

Tuberculosis (TB) transmission most commonly occurs in congregate settings where people with unsuspected, undiagnosed or inadequately treated TB or drug-resistant TB [DR-TB] come for services and move through crowded indoor spaces. Risk of TB transmission is particularly high in health care settings where people spend extended periods of time in waiting areas and share the air with other individuals seeking care. Infectious *Mycobacterium tuberculosis* [*MTB*] aerosols generated by people with unsuspected or inadequately treated TB can remain suspended for hours. A package of preventive and control strategies can be implemented in an overall TB transmission control plan. The controls hierarchy includes Administrative, Environmental and Respiratory Protection measures.

Administrative controls **(or work practice controls)** should be implemented as a first priority because they have been shown to reduce transmission of TB in health-care facilities. Such controls are a vital part of sound infection control practices, which require people with TB symptoms to be promptly identified, separated and treated. The physical separation of TB patients or people suspected of having TB requires rational design, construction or renovation, and use of buildings.

Environmental controls include methods to reduce the concentration of infectious respiratory aerosols (i.e. droplet nuclei) in the air, and methods to control the direction of infectious air. The choice of environmental controls is intimately related to building design, construction, renovation and use, which in turn must be tailored to local climatic and socioeconomic conditions. Environmental controls include: ventilation (natural, mechanical and mixed-mode) to dilute concentrations of organisms and exhaust them outside; filtration to capture infectious particles; and *germicidal ultraviolet (GUV) with air-mixing systems (previously known as ultraviolet germicidal irradiation, [UVGI]),* which inactivate these airborne organisms as they pass through the irradiated upper room of occupied spaces and disinfected air returns to the occupied zone. GUV compliments building ventilation, both mechanical and natural, but can also be the main means of air disinfection where mechanical ventilation is absent or functions poorly, and natural ventilation is limited.

Personal protective equipment (PPE) (particulate respirators) should be used together with administrative and environmental controls in situations where there is an increased risk of transmission.

There are administrative components to Environmental and Personal protective equipment controls.

Purpose of Upper-Room GUV Air-Mixing System

In many high-risk settings, ventilation is not available or adequate to dilute, remove or irradiate infectious *MTB* aerosol in crowded, occupied areas. Recent studies (Mphaphlele et al, 2015, Escombe et al, 2009) have shown that risk can be reduced by at least 80% for well-designed and well-maintained upper-room GUV air-mixing systems. In order to obtain the full value of the investment in this environmental control, proper installation, commissioning before use, and regular maintenance to keep the system operating as designed are critical for sustainability.

Building Owners/Operators Intent for GUV

This document assumes that the IPC committee or some other entity within a facility has:

1) Started the Commissioning process by completing an assessment of the building with a qualified infection control professional knowledgeable about GUV technology to determine areas where upper-room GUV is needed as a supplement to available ventilation (mechanical, natural or hybrid).
2) Questions of available electric power and capacity in the electrical system were positively addressed to ensure continuing function during outages.
3) A plan was developed which shows where upper-room GUV fixtures are to be installed.
4) Upon installation of the upper-room GUV system, the commissioning process was followed to ensure the GUV fixtures are installed and operating according to manufacturer's specifications, as well as measured for occupant safety and required upper room output.

The results of this performance evaluation in the commissioning process are documented in a report which includes:

1) The maintenance plan and budget
2) Original design of the system and instructions on installation per manufactures' manuals for the various models of GUV fixtures installed and other specifications; with design criteria
3) An "as built" version of 2) documentation of where each upper-room GUV Fixture was place and verified after installation;
4) Baseline readings of output after 100 h of operation;
5) Safety measurements in the occupied zone for each fixture with notes on any adjustments needed
6) Contact information for the GUV consultant and manufacturer for future follow up. If this information is not currently available, or if in the planning stages of a GUV system design, this maintenance manual will help build documentation of the as built conditions for ongoing maintenance and continuity of institutional memory.

Maintenance Manual Focus

The focus of this manual is to describe what is necessary to sustainably maintain an upper-room GUV system. Maintenance is defined as actions necessary for retaining or restoring a piece of equipment, machine, or system to the specified operable condition to achieve its maximum useful performance. Further it includes corrective (reactive) maintenance and preventive maintenance. Reactive maintenance covers immediate action necessary to troubleshoot a system failure, (e.g., a light burns out and needs replacement or the light flickers and needs a new ballast) and in response to reports on possible occupant overexposure in the occupied zone. Preventive maintenance is a systematic, scheduled review of the equipment with regular cleaning and replacement of parts at the end of useful life and measurement of output and safe operation. This manual will discuss how to develop a maintenance plan, how the plan should be implemented and who should be responsible for insuring the plan is sustained. This information is provided for use by service companies; governmental/oversight groups for verification; and healthcare (both hospital and community based), correctional facilities' in-house medical and maintenance staff or manufacturer.

DEFINITIONS

Administrative controls (or work practice controls) should be implemented as a first priority because they have been shown to reduce transmission of TB in health-care facilities. Such controls are a vital part of sound infection control practices, which require people with TB symptoms to be promptly identified, separated and treated. Managerial measures that reduce the risk for exposure to persons who might have TB disease. Examples include coordinating efforts with the local or state health department; conducting a TB risk assessment for the setting; developing and instituting a written TB infection-control plan to ensure prompt detection, airborne infection isolation (AII), and treatment of persons with suspected or confirmed TB disease; and screening and evaluating health-care workers (HCWs) who are at risk for TB disease or who might be exposed to *M. tuberculosis*.

Commissioning process: A quality-focused process for enhancing the delivery of a project. The process focuses upon verifying and documenting that the facility and all of its systems and assemblies are planned, designed, installed, tested, operated, and maintained to meet the owner's project requirements. (See owner's project requirements.)

Environmental Controls: include methods to reduce the concentration of infectious respiratory aerosols (i.e. droplet nuclei) in the air, and methods to control the direction of infectious air. The choice of environmental controls is intimately related to building design, construction, renovation and use, which in turn must be tailored to local climatic and socioeconomic conditions. Environmental controls include: ventilation (natural, mechanical and mixed-mode) to dilute concentrations of organisms and exhaust them outside; filtration to capture infectious particles; and *germicidal ultraviolet (GUV) with air-mixing systems (previously known as ultraviolet germicidal irradiation, [UVGI]),* which inactivate these airborne organisms as they pass through the irradiated upper room of occupied spaces and disinfected air returns to the occupied zone. GUV compliments building ventilation, both mechanical and natural, but can also be the main means of air disinfection where mechanical ventilation is absent or functions poorly, and natural ventilation is limited.

GUV*: *(Germicidal UV): see UVGI.

***Germicidal (UV-C) lamp*:** low-pressure mercury vapor lamp with a bulb, which transmits bactericidal UV-C radiation. (See further UV-C).

***GUV Meter (radiometer)*:** an instrument used to measure radiometric quantities, particularly UV irradiance or fluence. For measuring low pressure germicidal lamps, a cosine-corrected filter on the detector with 254 nm filter, with a range from 0.01 $\mu W/cm^2$ to 2000 $\mu W/cm^2$.

Infection prevention and control (IPC): Evidence-based practices and procedures that, when applied consistently in healthcare settings, can prevent or reduce the risk of transmission of microorganisms to healthcare workers, other residents, and visitors.

Fixture (also interchangeable with fixture): apparatus which distributes, filters or transforms any [visible]light and [or germicidal UV] transmitted from one or more lamps and which includes, except the lamps themselves, all the parts necessary for fixing and protecting the lamps and, where necessary, circuit auxiliaries together with the means for connecting them to the electric supply.

Maintenance: Actions necessary for retaining or restoring a piece of equipment, machine, or system to the performance to achieve its maximum useful life. It includes corrective (reactive) maintenance and preventive maintenance. Source: http://www.businessdictionary.com/definition/maintenance.html#ixzz4CbenRqVX

Mycobacterium tuberculosis: The namesake member organism of *M. tuberculosis* complex and the most common causative infectious agent of TB disease in humans. In certain instances, the species name refers to the entire *M. tuberculosis* complex, which includes *M. bovis, M. africanum, M. microti, M. canetti, M. caprae,* and *M. pinnipedii*.

Personal protective equipment (PPE) Personal protective equipment (particulate respirators) should be used together with administrative and environmental controls in situations where there is an increased risk of transmission.

Tuberculosis (TB) disease: Condition caused by infection with a member of the *M. tuberculosis* complex that has progressed to causing clinical (manifesting symptoms or signs) or subclinical (early stage of disease in which signs or symptoms are not present, but other indications of disease activity are present [see below]) illness. The bacteria can attack any part of the body, but disease is most commonly found in the lungs (pulmonary TB). Pulmonary TB disease can be infectious, whereas extrapulmonary disease (occurring at a body site outside the lungs) is not infectious, except in rare circumstances. When the only clinical finding is specific chest radiographic abnormalities, the condition is termed "inactive TB" and can be differentiated from active TB disease, which is accompanied by symptoms or other indications of disease activity (e.g., the ability to culture reproducing TB organisms from respiratory secretions or specific chest radiographic finding).

TB Case definitions:

•A bacteriologically confirmed TB case is one from whom a biological specimen is positiveby smear microscopy, culture or WRD (such as Xpert MTB/RIF). All such cases should be notified, regardless of whether TB treatment has started.

•A clinically diagnosed TB case is one who does not fulfil the criteria for bacteriological confirmation but has been diagnosed with active TB by a clinician or other medical practitioner who has decided to give the patient a full course of TB treatment. This definition includes cases diagnosed on the basis of X-ray abnormalities or suggestive histology and extrapulmonary cases without laboratory confirmation. Clinically diagnosed cases subsequently found to be bacteriologically positive (before or after starting treatment) should be reclassified as bacteriologically confirmed.

Bacteriologically confirmed or clinically diagnosed cases of TB are also classified according to:

−anatomical site of disease;
−history of previous treatment;
−drug resistance;
−HIV status.

TB contact: A person who has shared the same air space with a person who has TB disease for a sufficient amount of time to allow possible transmission of *M. tuberculosis*.

Ultraviolet germicidal irradiation (UVGI) (See GUV): the use of ultraviolet C (UV-C) energy, through a system designed to deliver UV-C, to inactivate microorganisms so they are no longer capable of replicating and causing adverse health effects. NOTE—UVGI: ULTRAVIOLET GERMICIDAL IRRADIATION. THIS IS A WIDELY PUBLISHED TERM. RECENTLY SOME ARE INTERCHANGABLY USING GUV. UV IS NON-IONIZING RADIATION.

UV-C: ultraviolet radiation with a wavelength between 280 nm and 100 nm. The "germicidal" UV wavelength (commonly 253.7 nm when generated using a low pressure mercury vapor lamp) falls into this UV band

SAFETY

Maintaining optimum UV dose to inactivate *MTB* while maintaining human safety from excessive exposure to UV-C energy from upper-room GUV systems is a primary concern in planning, commissioning, operating and maintain these devices. Well planned, installed, commissioned, operated and maintained upper-room GUV systems have been safely used throughout the world; however, human error, poorly installed fixtures or the wrong type of fixture have caused temporary, painful eye and skin irritation which resolved within 24-48 hrs. No long-term effects of GUV exposure are known (Nardell et al., 2008). As a part of the strategy for developing the maintenance and operating plan for your facility's GUV system, see the section, GUV Emission Performance and Safety Measurements of this manual which describes how to measure the eye level irradiance level UV-C level to determine if accumulated exposure over an 8 h period exceeds 6 mJ/cm^2 (American Conference on Governmental Industrial Hygienists (ACGIH) 2015), (Commission International de L'Eclairage (CIE) 2003). During a national field trial of upper-room GUV, the Tuberculosis Ultraviolet Shelter Study (TUSS) (1997-2004), 1200 upper-room GUV fixtures were installed in fourteen homeless shelters of various types, in six U.S. cities. Only one case of excessive exposure occurred when a double decked bed was moved too close to an upper-room GUV fixture. This human exposure problem was resolved when the fixture was relocated (Nardell et al., 2008). UV-C monitors were worn by nurses in a Boston hospital equipped with GUV fixtures in patient rooms. Over the course of several days, the daily accumulated UVC dose was a fraction of the allowed 6mJ/cm^2 (First, 2005). A further consideration for safety is the fixture design and output, for example, open, non-louvered fixtures should be used in spaces with ceiling heights over 2.7 m (9 ft.) while louvered fixtures for space with ceiling heights of 2.4 m (8 ft.). Other features of safety switches being installed in the fixture to de-energize the fixture when it is opened.

KEYPOINT: *With proper installation, training in use, signage, and safety measurements by trained personnel using PPE, GUV systems can operate with human safety.*

KEYPOINT: *Maintenance personnel must be trained to use PPE, e.g., safety glasses, when working within the GUV treatment zone [which extends from the bottom of fixture to the ceiling).*

EXAMPLES OF SIGNAGE PLACE IN THE FACILITY WHERE UPPER-ROOM GUV FIXTURES ARE INSTALLED AND WHICH SHOULD BE MULTILINGUAL AS NEEDED:

CAUTION

HIGH INTENSITY GUV:

TURN OFF LAMPS BEFORE ENTERING UPPER ROOM

CAUTION

HIGH INTENSITY GUV:

PROTECT EYES AND SKIN

UVGI (GUV) FIXTURES SYSTEMS

GUV fixtures vary based on make, model, efficiency and manufacturer. Care must be taken to follow all manufacturers' recommendations for maintenance and repair. There are however standard or universal maintenance procedures that need to be followed in order to maintain the efficacy and effectiveness of the fixtures. A visual inspection wearing appropriate eye protection should be performed periodically and if a lamp failure (lamp is not lit) is observed, corrective action should be taken *immediately* to return the fixture to service.

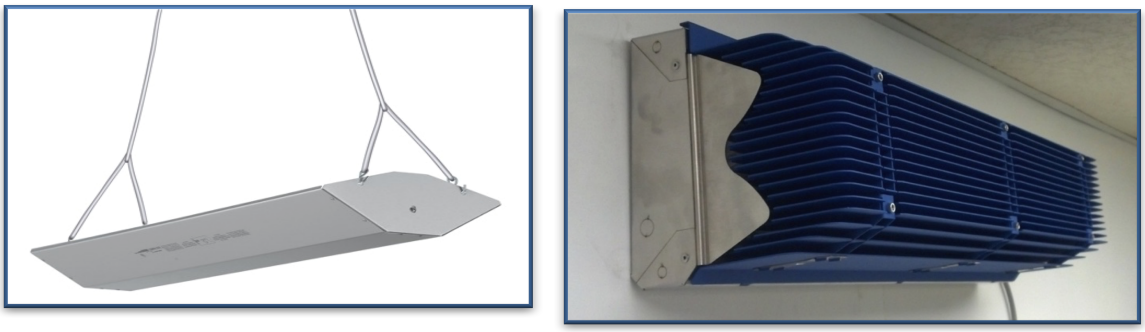


Figure 1 (Top left) Example open upper-room GUV fixture for spaces with ceiling heights 2.7 m (9 ft) or above. (Top right) Example of a louvered upper-room UVGI fixture for spaces 2.4 m (8 ft) (or greater in height).

COMPONENTS OF A SELECTED UPPER-ROOM GUV FIXTURE

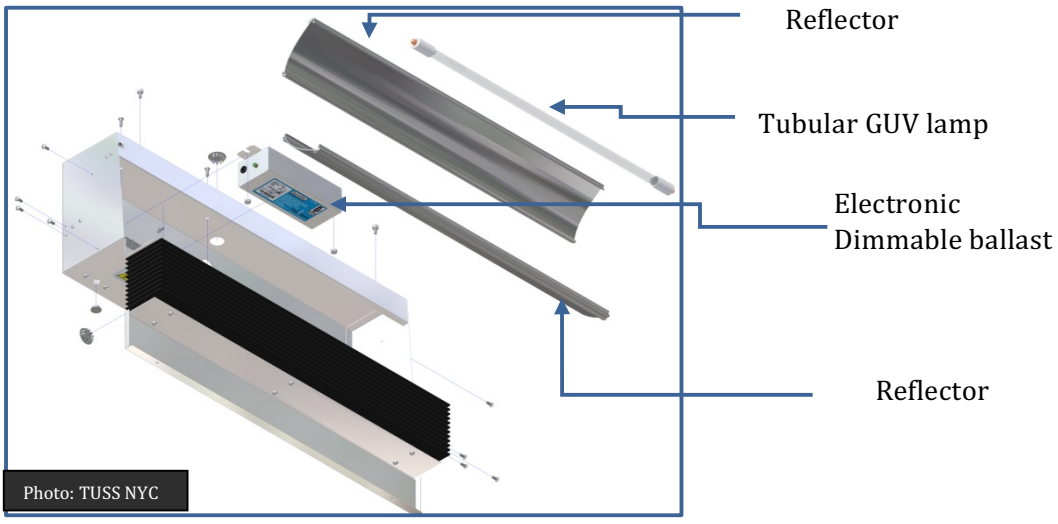
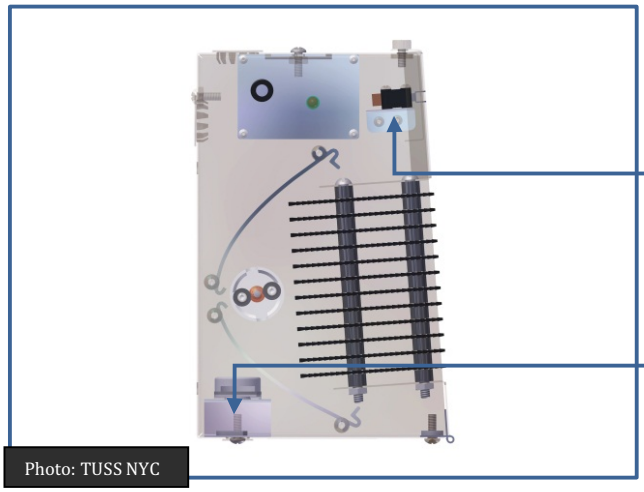


Figure 2 A&B: Components of wall -mounted louvered upper-room GUV fixture, in an expanded view(above) and in cross-section (below).



LAMP (SPECTRUM, REAL VS BOGUS, USEFUL LIFE, CHARACTERISTICS)

Although other GUV sources exist, currently the most efficient UV-C lamps are low-pressure mercury vapor discharge lamps. These lamps contain mercury, which vaporizes when the lamp is lighted. The mercury atoms accelerate because of the electrical field in the discharge colliding with the noble gas, and reach an excited state (Figure 3). The excited mercury atoms emit almost 85% of their energy at 253.7 nm wavelength. Very little energy is emitted in the visible region, so the remaining energy results in other various wavelengths in the UV region (mainly 185 nm) (Figure 4). However, quality UV-C lamps used for upper room GUV applications are treated with an interior coating that prevents any vacuum UV (200 nm and below) from being emitted from the lamp, so ozone production is not an issue. Poor quality UV-C lamps will produce ozone. Replacement UV-C lamps need to be non-ozone producing. Recycling of used UV-C lamps should comply with national and local environmental regulations based on manufacturer's documentation of mercury content within their UV-C lamps.

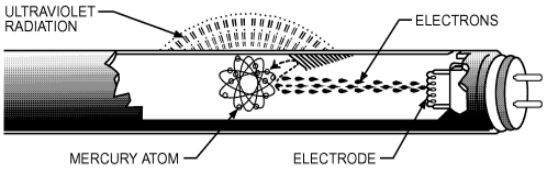


Figure 3 Function of vaporized mercury atom releasing UV from a germicidal lamp. Photo: IESNA

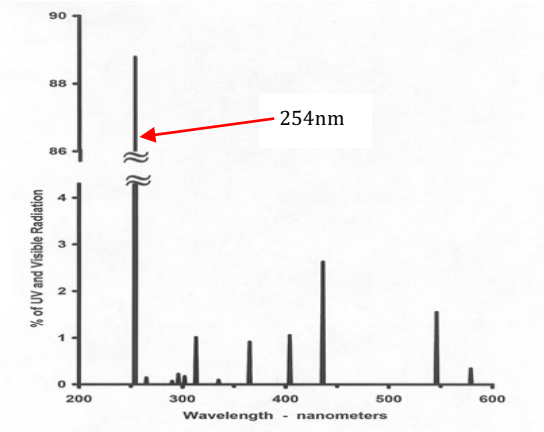


Figure 4 Spectral output of low pressure mercury vapor UV-C lamp. Photo: Robert E. Levin

UV-C lamp life varies by type, manufacturer, and operating characteristics. The majority of the UV-C lamps currently available have a rated effective life of 6,000-10,000 or burning hours. Some newer lamp and ballast combinations are now being rated at 18,000 hours. Consult the manufacturers' recommendations regarding the effective lamp life based on the ballast and other performance measures, such as temperature. The overall life of the lamp will be affected by voltage, starts and stops, depending on the ballast used to start and maintain the flow of electricity, so allowing the lamps to run continuously is beneficial to lamp life. The life of the lamp is dictated by the breakdown of the electrodes (or filaments)

in the lamp and the degradation of the quartz. When a lamp fails due to an electrode breakdown the lamp typically does not light and the failure is obvious. *When the lamps output declines, the lamp will continue to "burn blue" even after its germicidal output has decreased below acceptable levels.* A UV meter (radiometer) is used to measure either the absolute or relative output from the fixture/ lamp as a method of monitoring the lamp's useful life. *Another cost effective way (depending on the local economy) is to set a fixed schedule for lamp replacements based on the manufacturer's recommendations.* If labor costs are low, regular monitoring of the output of the fixtures can extend the useful life of the lamps as discussed later in this document.

A GUV lamp experiences an initial output decline during the break-in period (about 100 hours), followed by a gradual output decline over its lifetime due to lamp solarization (frosting) and metal deposition on the inner surface. Near the end of its life, even if UV light is hardly being emitted, you might see blue light from the fixture. This is why it is important to know what the baseline output of your fixture is and to check the output regularly to know when to change the lamp

- Annual lamp emission decline observed (First et al., 2007b):
  - Average 16% decline for linear tube lamps
  - Average 26% decline for folded (compact) lamps

Ballast

A ballast controls the electrical flow to the lamp in the fixture. Ballasts used in GUV Fixtures are identical to those used in a standard fluorescent lighting fixture in design and purpose. Electronic ballasts come with a built-in starter—some can be dimmed. The electronics also allow adjustment to different voltages and various fluctuations from interrupted power supply. The dimmable ballast allows adjustments to installed GUV fixtures when required for safety purposes. A ballast failure is easily recognized and diagnosed. A fixture that does not function after the lamp is replaced may have a ballast that has failed or it could be the voltage being supplied to fixture. The majority of the ballasts available have no serviceable parts so they must be replaced. Care must be taken to match the ballast with the electrical specifications of the lamp. If the wrong ballast is used the lamp may ignite, but its life and efficiency may be compromised. Follow all manufacturers' recommendations regarding replacement parts and wiring instructions.

It is strongly advised to use the ballast for recommended by the manufacturer for each lamp type because less than optimum conditions will affect the lamp's starting characteristics, GUV output, and operating life.

FIXTURE

Many GUV fixtures are made of either stainless steel or aluminum. These materials are resistant to degradation overtime to high, long-term exposure to intense UV-C radiation. Paint on sheet metal or power coated onto louvers can degrade with prolonged UV-C exposure. Stainless steel is less likely to deform overtime; while aluminum allows for a lighter weight important for mounting and shipping costs. Wiring, inside the fixture needs to be shielded from UV-C exposure to keep from becoming brittle. Fixtures need to be designed to allow easy cleaning and maintenance of louvers, lamp, ballast, and reflector.

SAFETY SWITCH/MOTION SENSOR/VIEW PORT, DIMMING SWITCH

Various features are specified which can make a safer environment for occupants and maintenance personnel, but add to cost and maintenance. A safety switch can turn off an individual GUV fixture for cleaning. A motion sensor can be provided to turn off a fixture if a

person rises above eye level to prevent accidental high intensity UV-C exposure. A viewport made of regular, non-transmissive UV glass can show whether or not a GUV lamp is lit. An additional sensor can be incorporated into the GUV fixture to provide feedback on output of the lamp. Some upper-room GUV fixtures have dimmable ballasts to reduce the initial emitted output of the fixture for safety, or as the lamp degrades in output overtime the dimmer can be adjusted to maintain GUV output. All fixtures need to meet the national electric code where they are installed.

VENTILATION

Research has shown that a well-mixed room air is essential for upper-room GUV effectiveness. (Xu et al., 2003) found an 80% effectiveness reduction without mixing. Many settings where mechanical ventilation is not available use low velocity ceiling paddle fans or oscillating wall fans. *When fans, mechanical ventilation or combinations are used, they must be maintained for an effective GUV system.*

PLANTS AND MATERIAL DEGRADATION

Low levels of germicidal UV inhibit photosynthesis in indoor plants which cannot tolerate these wavelengths. Plants should be kept below the upper room UV treatment zone. As with exposure to UV in sunlight, UV-C energy can fade and degrade organic material over time. This should be considered under facility maintenance.

DEVELOPING A MAINTENANCE PLAN

It is essential to have a written document for maintaining the installed upper-room GUV air-mixing system as designed. This document will serve as the guide to maintenance of GUV-air mixing systems, whether performed in-house or outsourced to a GUV service maintenance company.

ELEMENTS OF A WRITTEN PLAN

DOCUMENTATION—KEEP A LOG BOOK

Record when upper-room GUV fixtures were installed, inspected, cleaned, moved, etc. Record GUV fixture output based on established cleaning frequency, typically every three to six months; however, frequency may vary depending on environmental pollution, climatic conditions, relative humidity and type of building ventilation system.

COMMUNICATION—ESTABLISH COMMUNICATION RESPONSIBILITIES

• If a GUV lamp burns out (or other problem is observed), who notifies the facilities maintenance or GUV service company?
• Once an upper-room GUV system is initiated, who is responsible for inspecting/replacing the lamp?
• If the individual responsible leaves the facility, how is the communication process altered?
• Upper-room GUV system maintenance and repair procedures should be incorporated into the existing facility maintenance procedures and monitored by the responsible TB IC staff for compliance.

COST OF MAINTENANCE

Procure an ongoing five year maintenance contract with purchase of upper-room GUV system to be provided service company trained in upper-room GUV maintenance or This should include cleaning on a set schedule, lamp replacement annually (or based on percentage drop in output) and for failures, upper-room GUV fixture cleaning/servicing with measurement for output and safety with a qualified GUV radiometer using a cosine-corrected UV-C 254 nm bandwidth detector following cleaning and lamp replacement. The service company would be required to have sufficient (~5%) supply of lamps and replacement parts, such as ballasts to keep the system operational.

Develop In-house maintenance plan and budget for facility staff and supplies/equipment: Procure GUV meter (radiometer and detector) (as described below) and a calibration service, cleaning supplies (gauze, swab saturated with 70% alcohol for cleaning lamps, cotton or disposable non-sterile exam gloves, safety glasses with side panels, brushes for cleaning fixture louvers, hand vacuum for potential insect and dust removal, etc.), replacement lamps and parts, replacement of worn out or defective Fixtures, including shipping and handling costs and mercury spill kits to clean up any mercury released if a UV-C lamp breaks during servicing. Include cost for disposal of the mercury lamps by a company (see http://almr.org/) specialized in waste management that protects the environment for pollution in this case with mercury. Generally, this is not needed if GUV lamp contains < 5mg Hg. Labor: routine labor such as fixture maintenance incorporated into routine physical labor; and/or dedicated labor such as quarterly or annual maintenance tasks with labor per fixture established and budgeted. Include the cost of recalibration of GUV meter according to manufacturer's specifications.

EQUIPMENT COSTS: GERMICIDAL UV EQUIPMENT FOR TB IPC

Equipment Costs: Germicidal UV Equipment for TB IPC				
Upper-room GUV shielded/louvered fixtures for low ceilings (2.4 m / 8 ft.)	$200-1,500	Per fixture	1	When installed at 2.1 m (7 ft.) (from the bottom of fixture to the finished floor), the maximum GUV eye level measurement should be 0.4 µW/cm^2. Cost ranges from US$ 200 to US$1500.
Upper-room GUV shielded fixtures for higher ceilings (>2.7 m / >9 ft.)	$200-1,000	Per fixture	1	When installed, the maximum GUV eye level measurement should be 0.4 µW/cm^2. Cost ranges from US$ 200 to US$1000.
GUV lamp	$15-100	Per lamp	1	Spare parts; cost ranges from US$ 15 to US$100. Some proprietary lamps are very expensive. 30W T8 GUV lamp on the low end and Atlantic & American UV on the high side.
GUV (UV-C) radiometer and one UV-C detector with 254 nm filter	$500 to 2,500	Per meter	1	Battery operated instrument recommended for 0.01-2,000 µW/cm^2
GUV radiometer and detector calibration (annual)	$300-400	Per radiometer calibration	1	

Adapted from WHO One Health Tool: Infection Control working group, November 2014.
http://www.who.int/choice/onehealthtool/en/
For more information, please contact: Ernesto Jaramillo, Global TB Programme at jaramilloe@who.int.
Note: Consult specific manufacturer's recommendation for mounting GUV fixtures.

IN-SERVICE TRAINING

- Initial training for the upper-room GUV system should be provided by a GUV trained consultant or manufacturer's representative employed to deliver the final installed and validated system.

• Thereafter, in-house staff should conduct annual in-service training of medical and maintenance staff on the purpose of the upper-room GUV system, precautions on how to work safely around the GUV system and how to report observed problems for troubleshooting.
• All new employees should receive training on the upper-room GUV system and safety as a part of their initial employment.
• Review with a service company and/or local staff any space usage changes that effect the upper-room GUV system
• On a needs basis (but no less than annually) review changes within the facility with the TB IC to see if upper-room GUV fixtures need to be redeployed or additional units be procured. Document changes agreed upon with TB IPC.

PRIMARY TASKS FOR MAINTAINING UPPER-ROOM GUV FIXTURES

Upper-room GUV fixtures will vary based on make, model, and manufacturer. Care must be taken to follow all manufacturers' recommendations for installation, maintenance and repair. There are however standard or universal maintenance procedures that need to be done in order to maintain the efficiency and effectiveness of the fixtures. A visual inspection wearing appropriate eye protection should be performed periodically and if a lamp failure is observed corrective action should be taken immediately to return the fixture to service. Major tasks discussed include:

- Emission (fixture output) performance and safety measurements
- Fixture and Lamp Cleaning
- Routine Inspections
- Repairs and Replacement
- Disposal/Cleanup of nonfunctional lamps, ballasts, fixtures.

MONITORING

PERFORMANCE (EMISSION) MEASUREMENT—handheld radiometers are used to measure irradiance for an acceptable level of GUV output and eye level safety from GUV fixtures. As a part of the overall commissioning process, during initial acceptance testing of the GUV installation, assess the fixtures after a 100 h seasoning (burn-in) of new UV-C lamps. After the 100 h seasoning period the lamp output will be stable and a baseline measurement taken for monitoring output of the GUV fixture overtime. At periodic intervals established based on how frequent the upper-room GUV fixture needs to be cleaned, the output will be measured before cleaning and compared to the baseline measurement. When the output measures <70% of the baseline measurement even after cleaning, change the lamp. After 100 h establish a new baseline for the fixture based on the new lamp.

SAFETY MEASUREMENT—direct human exposure to ultraviolet germicidal irradiation exceeding the Threshold Limit Value (TLV) of 6mJ/cm^2 per 8 h established by the ACGIH and ICNIRP can result in painful eye and skin irritation[i]. This limit can be reached within a few seconds or accumulated over several hours if proper precautions are not followed to limit exposure. The cornea of the eye is the most sensitive organ to GUV over exposure, therefore, for lower room safety, in most cases eye level irradiance should be no more than 0.4 μW/cm^2 at 1.7m above the finished floor anywhere in the room, measured with a sensitive UVC, 254 nm radiometer. In certain areas such as corridors where occupants are passing through, values above the 0.4 μW/cm^2 may be possible with allowable safety because of the brief time spent in the corridor. Similarly, in areas such as ICUs, waiting areas,

patient rooms, congregation halls, nurses stations etc. where room occupants may be highly sedentary or even supine, irradiance levels below should be considered.

UV levels can be measured with a UV radiometer directly facing the device at eye height at various locations in a room, and must be taken in the same location each time. Depending on the type of areas and length of occupancy if the readings indicate eye-level irradiance consistently much over 0.4 μW/cm^2, especially with occupant complaints of eye irritation, the UV systems must be deactivated until adjustments can be made or the manufacturer can be contacted. Sloped ceilings have been associated with excessive lower room GUV levels

HAND HELD GUV (UV-C) METER—(RADIOMETER) FOR MONITORING

A radiometer (GUV meter) with a cosine corrected filter mounted on a detector with a narrow band filter at 254 nm, are used for GUV measurements in the field as shown in Figures 3 and 4. The diffuser also serves as an attenuator and, therefore, prevents detectors from damage and saturation while working at high intensity levels.

Maintenance Requirement for GUV (UV-C) Meter (Radiometer)

Recommend-calibration of meter according to manufacturer's recommendation.

3a)

Figure 4 a) Handheld UV-C Radiometer (Zenith Below) measuring UV-C output of fixture. Photo(s): Atlantic Ultraviolet

4a)

Figure 3 Handheld UV-C Radiometer with matching detector and filter. Photo: 3a) Gigahertz-Optik 3b) International ILT 2400 UV-C Radiometer is shown below. Photo: ILT.

3b)

4b)

MEASUREMENT STEPS

1. GIV radiation measurements should be taken
• At initial installation
• Whenever new tubes are installed (newer tube designs may have increased irradiance)
• Whenever modifications are made to the upper-room GUV system or room (e.g., adjustment of fixture height, location or position of louvers, addition of UV-absorbing or -reflecting materials, room dimension changes, modular partition height changes).
• Whenever the upper-room GUV fixtures are cleaned.
• Whenever any complaints of possible overexposure are received.
2. Assemble a measurement kit including:
a. Tape Measure for string or stick at 1 m or 3 ft.
b. GUV Meter with 254 nm detector (radiometer) with extension wand to hold sensor
c. Ladder
d. Safety glasses with side panels
e. N95 or FFP2 Respirator in high risk areas
f. A log book containing forms to document reason for measurement (new lamp, scheduled maintenance)
i. Eye level irradiance in occupied zone
ii. Fixture maximum output at 1 m distance from fixture (irradiance?)
g. Labels
3. Document any adjustments made during measurements (i.e., cleaning, reflector, changing lamp)
4. Making Measurements
h. Don all necessary PPE (respirator and safety glasses)
i. According to GUV meter's (radiometer) manufacturer's instructions, Zero the UV meter with the cap on the sensor.
j. Remove the cap and position the sensor 1 m from the back of the upper-room GUV fixture.
k. **For output measurements** (see Figure 5) raise the sensor up and down at midpoint of the fixture face to find the maximum output from the beam.
l. Record the reading in the log book. Note whether this is a baseline reading for comparison to future readings. (see example log recording form below).
m. If the measurement is not a baseline reading, compare it to the initial baseline reading. If the value is less than 70% of the original value, take corrective action by cleaning the lamp and fixture. Re-measure, and if the value is still below 70% of the original value, relamp the fixture. Take an eye level safety reading at 1.7 m to insure the relamped fixture can be left on for the required 100 h seasoning. If not take corrective action by adjusting the reflectors. If the eye level safety reading is less than or equal to 0.4μW/cm^2 in the occupied zone the system is safe for operation (Nardell 2008).
n. **For safety measurements** (see Figures 9-11) scan the sensor at eye level (1.7 m above the finished floor) toward various upper-room GUV fixtures in the field of view. Do this at various locations where multiple fixtures combine energy. Note if any areas in the scanning rise above 0.4μW/cm^2. If so, take corrective measures. Place the sensor where medical staff are seated and at patient beds to see if any excessive reading result. If so, take corrective measures. Corrective measurements can be adjusting louvers, painting surfaces with UV non-reflective paint, dimming the GUV ballast if available.
o. Record the readings of individual fixtures in the logbook recording form. Note whether corrective actions were taken or further action is required.
p. See figures 6-8 for examples of techniques for measurement.
5. Document and Sign-off.

Figure 5 (above) Illustrates use of measurement tape to indicate 1 m distance from the back of the GUV fixture to the sensor. Detector (left) is raised and lowered to find maximum output (irradiance) of the UV beam for recording output. If allowed, permanent marker on the floor would facilitate repeat measurement. Or use as a yard/meter stick between the face of the fixture and the GUV radiometer's detector.

Figure 6 Technician checking eye level safety with GUV radiometer. Note: the blue visible light is not GUV only the radiometer can accurately assess GUV.

Figure 7 GUV safety readings at eye level in patient room.

Figure 8 Technician measuring GUV eye level safety in corridor.

Facility:	**Room Name:**				
Irradiance ($\mu W/cm^2$)	**Acceptance Criteria** XX =($\mu W/cm^2$@1m)	**Record Quarterly Readings (Pre and Post Cleaning)**			
		Quarter 1	**Quarter 2**	**Quarter 3**	**Quarter 4**
Fixture ID: Model/Manufacturer Installed:	Less than 70% of xx				
Fixture ID: Model/Manufacturer Installed:	Less than 70% of xx				
Fixture ID: Model/Manufacturer Installed:	less than 70% xx				
Lower room:	≤0.4$\mu W/cm^2$				
Model and Serial number of UV-c meter: Date of Calibration					
Date:					
GUV lamps replaced/Date:					
Comments:					
Approved by:	Name: Signature:				

FIXTURE AND LAMP CLEANING

Accumulation of dust on the reflective surfaces and lamps of upper-room GUV fixtures accounts for a significant decline in performance. Fixture cleaning and maintenance shall be performed in accordance with the fixture manufacturer's recommendations. In the absence of manufacturer's instructions, the following guidance should be followed in order:
• Assemble a cleaning kit consisting of:
• Clean powder-free gloves
• Soft, lint-free cloth
• 70% ethyl or isopropyl alcohol
• Hand held vacuum, brush for louvers
• Safety glasses
• PPE: N95 or FFP2 respirator in high risk areas
• Submit form to supervisor to document cleaning and re-measurement of output
• Don protective personal equipment before entering irradiated zone or opening upper-room GUV devices.
• Turn off fixture and allow lamps to cool
• Use a dry lint-free cloth to remove any dust from external surfaces and between louvers use a brush and vacuum.
• Open unit as stipulated by manufacturer
• Handle lamps with clean powder-free gloves to prevent oil deposits on lamps and reflective surfaces
• Change GUV lamps according to a prescribed schedule or if indicated by the routine performance monitoring.
• Change failed ballasts of flickering lamps
• Use a lint-free cloth dampened with 70% ethyl or isopropyl alcohol to clean GUV lamps and reflectors (NOT SOAPY WATER). Carefully apply pressure to remove stubborn dirt
• Wipe GUV lamps, reflectors, louvers and external surfaces with a clean, lint-freelcloth
• Close upper-room GUV fixtures properly
• Turn on the system and verify GUV lamp operation using eye protection
• Make sure the upper-room GUV fixture is dry and then re-measure for output and safety
• Record inspection, cleaning and replacement in maintenance logbook as recommended.

Frequency of Cleaning will depend on local conditions. The maximum reasonable maintenance interval for cleaning and monitoring interventions would typically be 3 months dirty/less clean environments and six months for clean. Frequency of cleaning will be site specific within facilities. This interval will differ depending on the type of ventilation (mechanical or natural) as well as environmental dust levels. The maintenance plan can be adjusted based on performance data obtained during routine monitoring.

1. Bring: a ladder, rubbing 70% ethyl or isopropyl alcohol, soft lint-free cloth, powder-free gloves, logbook, GUV meter, measuring tape, new GUV lamps, screwdriver (flathead, Philips or special tool recommended by manufacturer). Wear safety glasses when GUV unit is energized. Wear PPE (respirator) when working in high-risk TB settings.

2. Turn off GUV unit and ***allow it to cool***.

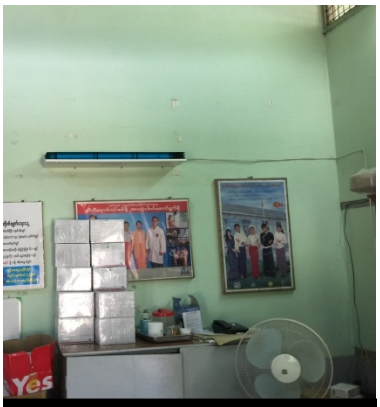


Photo: Richard L. Vincent

Photo: Richard L. Vincent

Photo: Richard L. Vincent

3. Open up the upper-room GUV luninaire and service. ***Wear powder-free gloves when handling the reflector and lamp.*** Wipe down the reflector and lamp with a clean, lint-free cloth using 70% ethyl or isopropyl alcohol to remove grime. Brush or vacuum louvers. Carefully replace clean lamp. Follow manufacturer's recommendation on GUV lamp replacement or based on measurement. *Comply with national environmental disposal regulations for breakage and recycling.*

Photo: Paul A. Jensen

Photo: Grigory Volchenkov

Photo: Paul A. Jensen

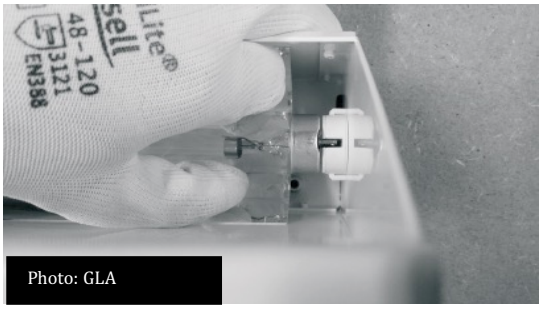


Photo: GLA

4. Close the upper-room GUV fixture. ***Only when safely standing in the lower room, switch on the upper-room GUV fixture*** and allow it to warm up for 10 minutes before recording output and safety measurements using a GUV detector and radiometer. Measure and record output and eye level safety values.

LAMP REPLACEMENT

GUV lamps and or their ballasts and starters can malfunction/fail at any time or can degrade gradually with time adversely affecting the lamp effectiveness, thus requiring replacement.

Economical replacement of lamps due to gradual degradation can be achieved through the routine performance monitoring using a GUV irradiance meter. For facilities with a large number of installed lamps and with the technical capacity to conduct a monitoring program, spot re-lamping based on individual device performance against the minimum functional criteria is recommended (70% of new seasoned output).

Where upper-room GUV installations are not sufficiently large to warrant the procurement and maintenance of a GUV radiometer, a group re-lamping strategy should be considered. Based on labor costs, annual lamp replacement may be more cost effective than performance monitoring.

The unexpected failure of mercury vapor lamps can be identified through the visual inspection of lamps when they are turned on. While the characteristic blue glow of these lamps is not a reliable indicator of GUV output, it will indicate whether a lamp or its control gear has unexpectedly failed. In devices with GUV lamp clusters, special consideration should be given to safely inspecting individual lamps for failure.

ROUTINE INSPECTIONS

Initial Observations:

Make sure that a trained professional installs the upper-room GUV fixture. Whoever does the installation should make sure that the fixture is properly mounted, but some questions to think about during the **initial inspection** include:

- Is the fixture level with the earth? Check both directions by placing a level parallel to the wall and perpendicular to the wall on top of the fixture.
- Are the electrical connections proper?
- Is the fixture securely and properly fixed to the wall/ceiling?
- Is the fixture pointing in the right direction?
- Is the fixture mounted high enough? The ideal height depends on the room height, but the fixture should be above 2.1 m (7 ft).
- Is it safe for occupants? Use a UVC detector to take measurements in the lower room (at height 5'8" or 1.7 m)

Daily observations:

- should be conducted during the initial upper-room GUV installation, and regularly after installation. *This should be added to the facility daily SOPs along with window management for example.*
- *A designated person to call if a light is out should be listed in the SOP.*

Routine inspection for operation and maintenance (every 3-6 months):

- Is the GUV lamp turned on? Do not turn off during the night; continuous operation can extend reported lifetime by up to 60% over manufacturers recommended life.
- Is it clean?
- Check maintenance log to make sure maintenance is not needed.

REPAIRS

▪ Establish defined, comprehensive replacement and repair agreement with the vendor or provide training to equip in-house facilities staff to perform these services.
▪ Keep track of warranties.
▪ Receive advance replacements and use packaging for return and repair of defective or damaged fixtures.
▪ If you experience an early lamp failure, make sure to get a replacement from the vendor. Annual lamp failure observed (after ~9000 hours):
▪ <1% for linear tube lamps
▪ <2% for folded lamps

DISPOSAL/CLEANUP OF NONFUNCTIONAL LAMPS, BALLASTS, FIXTURES.

GUV lamps should be treated the same as other mercury-containing devices, such as fluorescent bulbs. Many lamps must be treated as hazardous waste and cannot be discarded with regular waste. Low mercury bulbs often can be discarded as regular waste if < 5 mg Hg; however, national codes classify these lamps as hazardous waste. The U.S. EPA's universal waste regulations allow users to treat mercury lamps as regular waste for the purpose of transporting to a recycling facility. This simplified process was developed to promote recycling. The most stringent of the regulations for disposal should be followed.

Most upper-room GUV systems currently depend on the use of an electronic ballast to provide the UV lamp with power; however, many older systems use magnetic ballasts instead. Magnetic ballasts manufactured before 1979 contain polychlorinated bi-phenols (PCB) in the dielectric of their capacitors. Recycling is the best way to dispose of magnetic ballast. The process allows the reuse of copper and aluminum wire, steel laminations, and steel cases, and it disposes of capacitors and potting compound as hazardous waste in high-temperature incinerators.

As electronic ballasts fail, managers should treat them as electronic waste. Many lamp and ballast recyclers are expanding their businesses and becoming certified to accept electronic waste. Some recyclers now accept both lamps and electronic ballasts.

SUMMARY

In conclusion, we have discussed various elements for developing a sustainable approach to maintaining GUV Systems in designed condition. A key decision will be whether to maintain the GUV with in-house staff where rigorous maintenance can extend the useful life of the lamps beyond the 9000 h of an annual re-lamping. This can be done; however, it requires dedication and close monitoring to make this approach work. If in-house staff is limited to carry out this rigorous maintenance, quarterly routine cleaning and semiannual measurements might prove a suitable approach with an annual re-lamping of all the fixtures. The other approach is to hire a company to perform GUV service maintenance.

The process measure for GUV is the continued functionality of the upper-room GUV air-mixing system over time. It should be integrated into the overall facility TB IPC measures. Functionality, will be measured based on being maintained and operated at designed output and safety. In a larger monitoring and evaluation system, based on the hierarchy of controls, GUV could be linked to reduced infections in the facility.

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