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RICE 360° Institute for Global Health

Low-Cost Ultraviolet Germicidal Irradiation (UVGI) System for N95 Masks in Low-Resource Settings

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Introduction and Rationale

The current practice for pandemic diseases transmitted by airborne particles is the use of respiratory personal protective equipment (PPE), of which the most common is the disposable N95 filtering face-piece respirator (FFR). However, these FFRs are typically disposed of after a single use to avoid contamination and the ongoing COVID-19 pandemic has led to a global shortage of these N95 FFRs.

One strategy to combat this shortage is to reuse the FFRs after proper decontamination. Recently, several groups have published protocols on the use of Ultraviolet Germicidal Irradiation (UVGI) for the decontamination of N95 masks. Yet, many of these protocols rely on commercial systems that are not so widely available across all medical institutions across the globe.

This document summarizes a UVGI system developed by Rice 360°, Malawi University of Science of Technology, and the University of Malawi – The Polytechnic that is designed for low-resource settings through the reuse of readily available and inexpensive materials.

According to the literature, UVGI exposures of 2-5 mJ/cm^2 are sufficient to inactivate coronaviruses on surfaces.[1-2] Most institutions using UVGI as an approach for N95 decontamination during the ongoing pandemic are using higher dosages to ensure adequate decontamination. Recently, most studies and implementations have cemented 1 J/cm^2 as the recommended dose for proper UVC decontamination and has become the current guidance.[3-4] Considering these guidelines, the system described in this manuscript is designed to deliver a minimum 1 J/cm^2 dose of UVC to all areas of each N95 mask being decontaminated in a single cycle. It is important to clarify that the recommended time of UV-C exposure for a dosage of 1 J/cm^2 ensures that all areas of a single mask receive that dosage, but other areas will receive a higher dosage. While our protocol describes a time of exposure for a 1 J/cm^2 dosage, the same exact lamp placement can be used to deliver a higher or lower dosage by changing the amount of time the masks are exposed to UVC light.

The illumination setup of this UVGI system consists of six G645T5L Germicidal bulbs (DAMAR) rated for 25 Watts of UV output at 254 nm. Each bulb is rated to produce an average of 200 $\mu W/cm^2$ at 1-meter distance. The current sent to the germicidal lamps is regulated by a two-lamp electronic instant start ballast (Robertson IAQ164G6HOMV). The system can be assembled with minimum expertise for around $800 USD.

Room Requirements and Safety Information

This UVGI system is designed for approximately a 4 ft x 5 ft (~1.2 m x 1.5 m) area.

While this is the recommended dimensions of the area, a smaller or larger area can be used, but the time taken for disinfection will increase in a larger area with greater distances between the lamps and the mask rack, or decrease in a smaller area with less distance between the lamps and the mask rack. No matter what the final size of the UVGI system is, the room used for the UVGI system requires the following features to address safety concerns:

- **Door that closes.** The room needs to have a door that closes — it will be critical that the door is not inadvertently opened during treatment as the light used presents a hazard to eyes and skin.
- **Safety signage.** It is recommended that the room has both signage and multiple exterior locking mechanisms and/or a person stationed outside the door while decontamination is underway to ensure the door is not opened while the lights are in use. See, Figure 1.1 for examples.

Figure 1.1 Examples of safety signage for the UVGI room.

- **Power source from outside the room.** The system requires a way to provide power to the UVC lamps from a source outside of the room. This can be accomplished with a plug or cord running either under the door or drilled through the wall. Locating the power outside the room allows the system to be powered on and off without exposing a person to the UVC light in the room.

Materials List

Quantity	Part Name	Picture	Quantity	Part Name	Picture
6	DAMAR G64T5L Germicidal Lamp		5	10 ft ½“ PVC Pipe	
3	Robertson IAQ264G6MV Electronic Instant Start Ballast		12	PVC Tee Connector	
10	901hor - sockets		2	PVC Elbow Connector	
1	Extension Cord		6	2”x4”x10” Wood	
1	UVC Light Meter/Datalogger **(IMPORTANT: Must be a UVC light meter attenuated for 254 nm)**		-	Aluminum Foil	
-	Duct Tape		-	Wood Screws	
-	Wire		-	Wire Nuts (as available)	

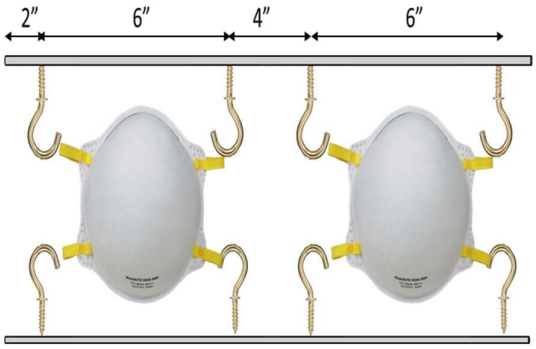
Recommended Tools

Quantity	Part Name	Picture	Quantity	Part Name	Picture
1	Wire Stripper and Cutter		1	Drill	
1	Hammer or Rubber Mallet		1	Saw to Cut Lumber	
1	PVC Cutter		-	-	-

Building a PVC mask rack

Key features: The PVC mask rack is where each mask will be hung in a way that holds each mask open during the disinfecting process. Holding the mask open is important to assure all surfaces of the mask receive disinfecting UVC.

These building instructions are for one rack.



Raw materials for the PVC mask stand:

No.	Description
5	½” 10 ft PVC pipe (~$2.00 each)
12	½” SCH 40 tee connector (~$3.69 for 10)
2	½” SCH 40 90 DEG Elbow connector (~$4.00)
72	Eyehooks self-tapping (~$5.00 per box of 32)
1	PVC Cutter
1	Hammer to secure PVC connections
1	Drill

To build a PVC mask rack

1. Gather tools and raw materials.
2. Cut the PVC into the following lengths using a PVC cutter:
   a) 6 each at 5-foot sections
   b) 10 each at 10-inch sections:
      i) 5 used on left side
      ii) 5 used on right side
   c) 2 each at 5.5-inch sections
   d) 4 each at 1-foot sections for the base
3. Drill holes in the 5-foot PVC sections for the eye hooks at the following locations. (A single mask will be placed in the center of 10-inch increments.) See, Figure 1.1.

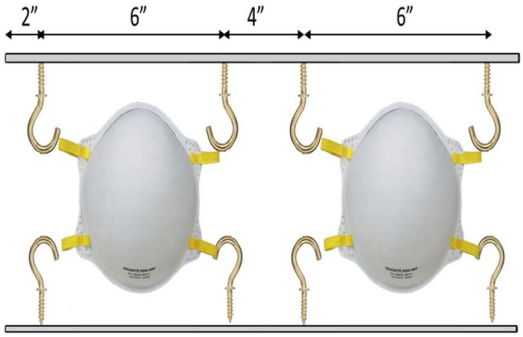


Figure 1.1: Diagram of eyehook spacing.

Note: The top and bottom 5-foot sections have holes only on the top or bottom of the PVC pipe; for all other sections, there will be a hole on the top and bottom. If it is easier to drill both holes at the same time, that is an option. See Figure 1.3 for an example.

   a) From the end of the 5-foot section next to where the elbow or tee connector will be placed, measure 2 inches toward the center of the 5-foot section, and then drill the first hole for an eyehook.
   b) From that hole, measure 6 inches toward the center, and drill another eyehook hole.
   c) From that second hole, measure 4 inches toward the center, and drill the third hole.
   d) From the third hole, measure 6 inches toward the center for the fourth hole.
   e) Continue drilling holes alternating 4-inch and 6-inch spacing until all holes are drilled for the length of the 5-foot section.

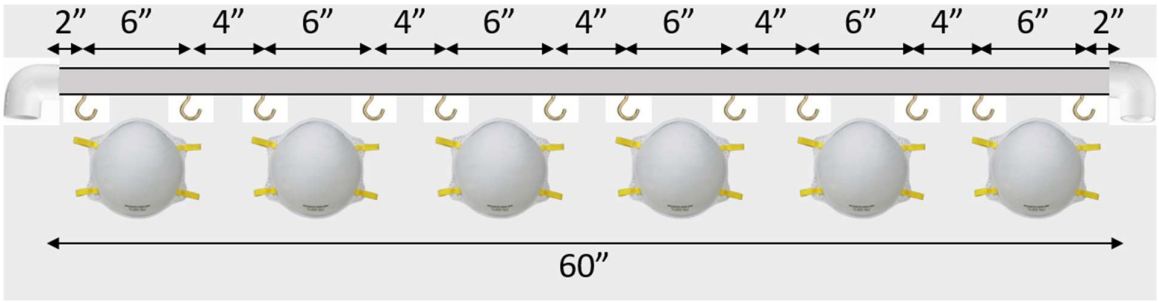


Figure 1.2 Diagram of spacing for eyehook holes across a 5-foot section.

4. Place the eyehooks into the drilled holes in sets of four, two on the bottom and two on the top, as shown in Figure 1.2.
5. For the top bar, connect two elbow connectors on either side of the 5-foot section. Connect a 9-inch section to each empty end of the elbow connector. See, Figure 1.3.
6. Connect to a tee connector to the other end of the 9-inch section, with the perpendicular portions of the tee connector on either side facing each other.
7. Connect another 5-foot section between the two tee connectors.

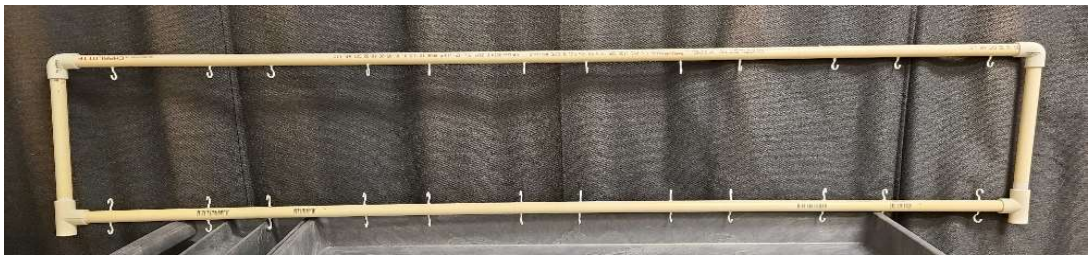


Figure 1.3 Single row of mask hangers.

8. Repeat the above process until there are six horizontal bars.
9. For the final horizontal bar, drill and connect the eyehooks into only the top of the 5-foot PVC segment. See, Figure 1.4.

Figure 1.4 Rows of mask hangers assembled together.

10. Build the base supports for the PVC frame by connecting a 5.5-inch PVC segment to the empty side of the bottom two tee connectors on each side of the PVC frame. Place a tee connector with the middle portion pointed up, and then connect 1-foot pieces to the two remaining sides of the tee joint to create feet for the legs. See, Figure 1.5.

Figure 1.5 Supports for the rack.

11. Lift the PVC frame up and stand it on this base. The frame should now be able to hold its own weight upright. See, Figure 1.6.

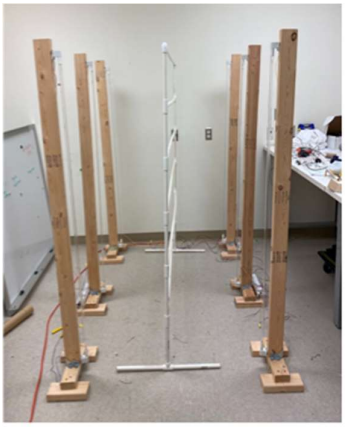
Figure 1.6 Completed rack placed in room.

Building and Placing the Wooden Lamp Stands (Six)

Key features: The wooden lamp stands hold the UVC lighting that will be used to disinfect the masks.

These building instructions are for

- building six wooden stands
- installing the electrical bulb sockets
- placing the lamp stands and mask rack in the room



Raw materials for the PVC mask stand:

No.	Description
6	2” x 4” x 10” lumber
12	901hor electrical sockets
-	Screws
6	Germicidal bulbs (see note)
1	Saw
1	Drill with appropriate drill bit

Note: The germicidal bulb selected should be 254 nm and rated to not produce ozone.

To build the wooden lamp stands

1. Gather tools and raw materials.
2. Using a saw, cut a single 2” x 4” x 10" piece of lumber into segments of the following lengths: two measuring 9 inches, one measuring 12 inches, and one measuring 66 inches.
3. Create a base by connecting 9-inch pieces of wood to either side of the 12-inch wood segment. See, Figure 2.1.

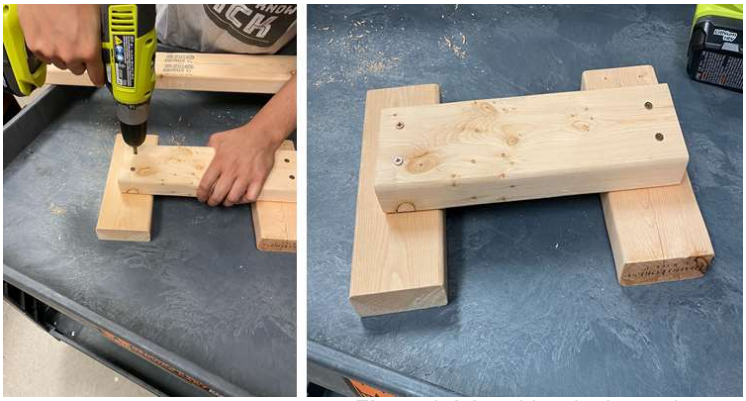


Figure 2.1 Attaching the base pieces.

4. Attach the 66-inch piece of wood perpendicularly to the 12-inch portion of the base of the lamp holder. This section will hold the long light bulbs. See, Figure 2.2.

Figure 2.2 Attaching the upright section of the stand.

To connect the electrical sockets to the lamp holder

1. Gather the electrical sockets, two for each stand.
2. Drill two pilot holes onto the 66-inch wood segment: one hole two inches from the bottom of the 66-inch wood segment and the second hole 61 inches away from the first hole.

Figure 2.3 Attaching the electrical light socket.

3. Insert a wire into the socket with the spring mechanism. Screw this socket into the first pilot hole closest to the base, ensuring the socket faces towards the top of the lamp holder and that the wire is accessible. See, Figure 2.3.
4. Insert a wire into the socket without the spring attachment. Screw the socket into the second pilot hole facing the bottom of the lamp.
5. Insert a germicidal bulb into the two sockets by first pressing the lamp down on the spring mechanism of the bottom socket and sliding the bulb into the top socket. See, Figure 2.4.
6. Repeat this process for all six lamp holders.

Figure 2.4 Completed stand with two sockets and bulb.

To place the lamps and mask racks in the room

1. As shown in Figure 2.5, designate a 4-foot-wide x 5-foot long space in the room chosen for the UVGI system.
2. Place the PVC mask holder in the center of the space.
3. Place three lamp holders on the right side of the mask stands so that each lamp is centered two feet away from the mask rack. Space each lamp equidistant from one another.
4. Repeat for the left side of the mask rack with the remaining three lamp stands.

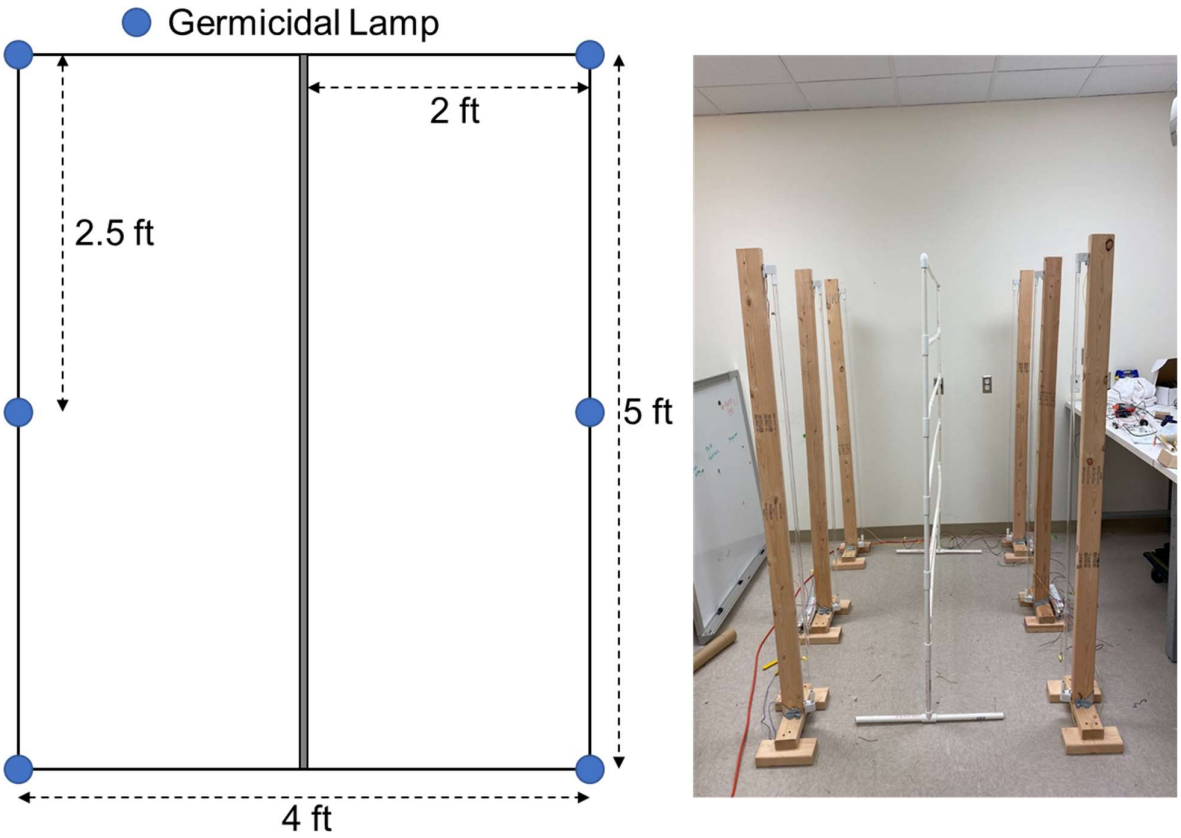


Figure 2.5 Placement of lamp stands and mask rack in the room.

Installing electrical components

Key features: The wooden lamp stands holding the UVC lighting will need to have ballasts installed for the lighting and an extension cord run outside the room, where the system will receive power.

These building instructions are for

- connecting the ballasts to the light sockets
- providing electrical power to the system

Raw materials for the PVC mask stand:

No.	Description
3	Ballasts
1	Extension cord
1	Wire strippers
-	Wire nuts (as available)
-	Wire
-	Cell phone or wireless camera for monitoring (as available)
1	Power strip (optional)

- It is advisable to consult with an electrician for wiring the ballasts and power cables.
- Different models of ballasts may have different wiring colors and configurations. Follow the directions included with the ballast being used.

The electrical components of the UVC system consists of three electric, instant start ballasts (Robertson IAQ264G6MV) that are each capable of regulating two germicidal bulbs.

To minimize excess wire and clear the field of illumination, wires were connected in the above configuration with lamp one and two being connected to ballast one, lamp three and four connected to ballast two on the back side of the system, and lamp five and six connected to ballast three on the outer left side of the system. See, Figure 3.1.

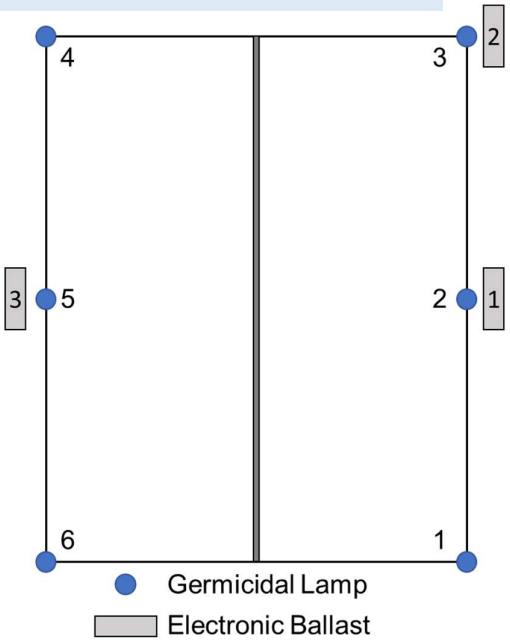


Figure 3.1 Placement of ballasts.

To connect two UVC lamps to each ballast

These instructions are for the Robertson IAQ264G6MV ballast. The wiring directions can vary for different ballast models. Please consult an electrician and follow the instructions for the ballast being used.

1. Gather the three ballasts, wire strippers, and all other necessary tools and supplies.
2. Connect the plugin wiring to a ballast. See, Figure 3.2.

Figure 3.2 Ballasts wiring.

3. Connect the first lamp to the ballast. For the ballast pictured, for example, the red wire from the ballast is wired to one wire from the socket mounted to the first lamp holder. The blue wire from the ballast has been wired to the remaining socket wire of the first lamp. See, Figure 3.3.

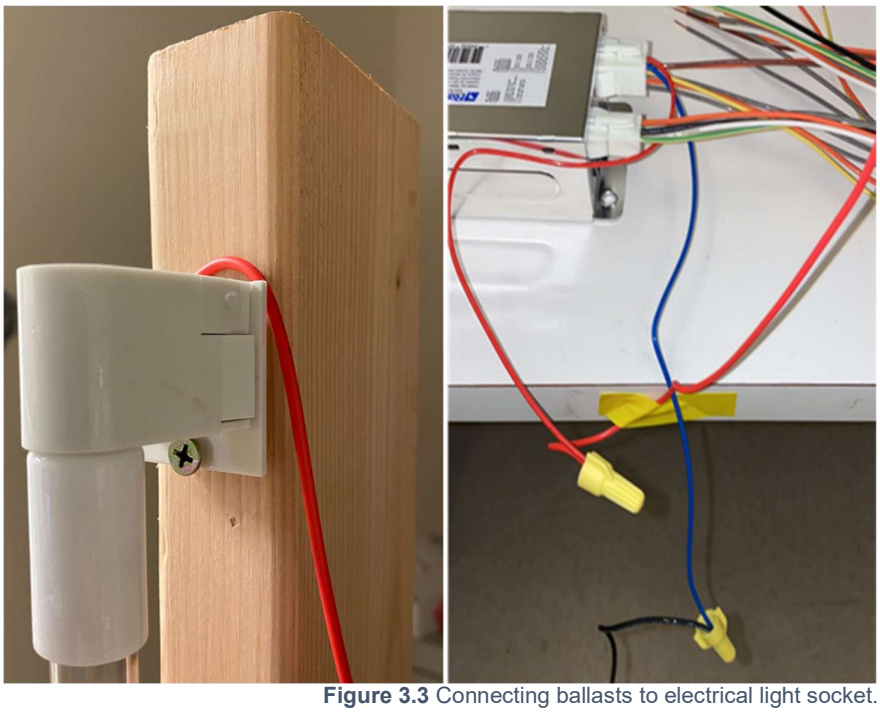


Figure 3.3 Connecting ballasts to electrical light socket.

4. Connect the second lamp to the ballast. Take the yellow wire from the ballast and wire it to one of the sockets of the second lamp. Take the brown wire from the ballast and wire to the remaining socket of the second lamp.

5. Repeat this process using the second ballast for the third and fourth lamps, and the third ballast for the with fifth and sixth lamps with the third ballast.
6. Continue to the next section for instructions on connecting each ballast to an extension cord.

To connect the power cable/extension cord to the lamps

1. Cut the female end of an extension cord, cutting back the shielding to reveal the wires.
2. Remove the outer coating of the wiring. Make sure not to cut the outer coating of the three wires inside. Strip the ends of each wire and twist the copper ends together. See, Figure 3.4.

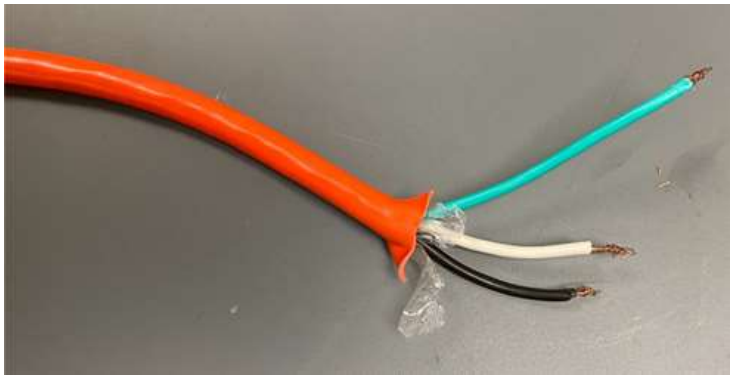


Figure 3.4 Preparing the extension cord.

3. Connect the ground, positive, and negative wires of the ballast and the extension cord. See, Figure 3.5.

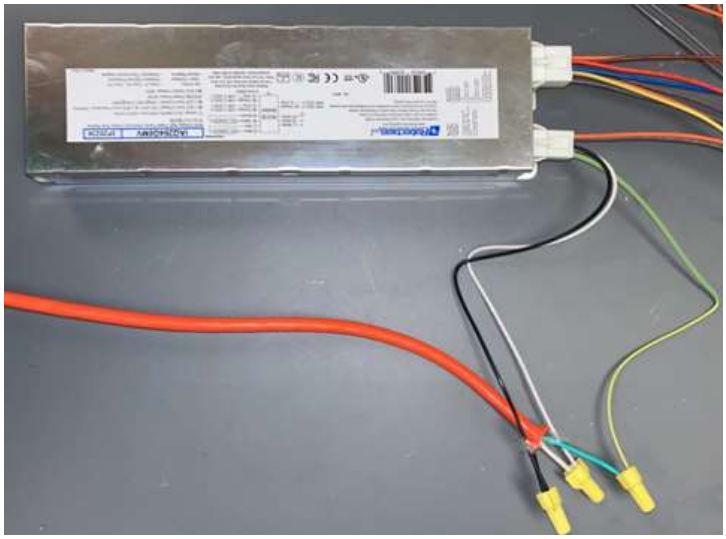


Figure 3.5 Wiring the extension cord to the ballast.

4. Repeat this process with the remaining two ballasts. Connect all ballasts to the positive, negative, and ground wires of the extension cord.
5. Take the black wire from each ballast and the black wire from the extension cord and join by twisting a wire nut in a clockwise direction until wires are firmly attached.
6. Repeat for the white wires of the ballasts and the white wire from the extension cord.
7. Repeat for the green wires of the ballasts and the green wire from the extension cord.

To ensure your system is functioning

1. As available, set up a camera or mobile phone to view the system while you are out of the room.
2. Ensure that the wall outlet/power strip used to provide power to the system is outside of the room where the UVC lamps are placed. It is important to be able to control power to the system from outside the room for safety.
3. Plug the extension cord into a surge protector or power strip that has a switch on it. (Alternatively, you can power this system by connecting the extension cord directly into a wall outlet that is located outside the room where the UVC lights are installed.) See, Figure 3.6.

Figure 3.6 Extension cord plugged into a power strip.

4. Turn on the switch on the power strip; the lights should turn on, but do not enter the room.

Figure 3.7 The video or picture test should show all the lights illuminated. It is a blue light.

5. Turn off the system.
6. View the video or photograph of the system captured in the last step. If fully functioning, your system should look like the lights do in Figure 3.7, with each bulb producing a blue light.

Adding reflective material

Key features: Once the system is built, placed in the room, and has electrical power, the next step is to wrap the system in a reflective material, such as aluminum foil, to direct the light toward the masks being sterilized by the UVC.

These building instructions are for installing the reflective material.

Raw materials for the PVC mask stand:

No.	Description
-	Aluminum foil
-	Duct tape
-	Cardboard box to make a door

Note: the cardboard door section can be assembled from other available materials if necessary.

To install the aluminum foil (reflective material)

1. Gather supplies and tools.
2. Using duct tape, attach the aluminum foil sheets between the back two lamp holders on the side of the wood closest to the N95 mask rack. Ensure the reflective side of the aluminum foil is facing the N95 mask rack. See, Figure 4.1.

Figure 4.1 Aluminum foil reflective surface installation.

3. Again, using duct tape, affix aluminum foil sheets between the back-left lamp stand and the front left lamp stand along the side of the lamp holder closest to the UVC bulbs. Ensure the reflective side of the aluminum foil is facing the N95 mask rack. Then, repeat for the right side of the system. See, Figure 4.2.

Figure 4.2 Aluminum foil reflective side walls.

4. For the front of the system, aluminum foil sheets can be taped between the two front lamp stands before a cycle and removed afterwards. Alternatively, you can create two cardboard doors for the side closest to the front of the UVC system, as shown in Figure 4.3. To create the doors:
   - Take a carboard box and cut one seam and flatten out.
   - Cover one side of the cardboard box with aluminum foil, ensuring the reflective side will face the mask rack once it is installed.
   - Tape one outside length of the aluminum covered box to the side of the lamp holder, allowing it to open and close.
   - Repeat for the other side of the UVC system.

Figure 4.3 Aluminum foil reflective front walls from carboard.

Testing and Validation

Before use, it is important to measure UVC light intensity at various masks positions and orientations to ensure an adequate dosage will be received at every given point.

Using specifically a UVC light meter attenuated for 254 nm (such as the SDL470: UVA/UVC Light Meter/Datalogger), measure the UVC light intensity for at least 45 seconds at each of the positions of the N95 respirator as shown below. In Figure 5.1, positions A, B, and C represent the front of the N95 mask, while D, E, and F represent the light intensity at the inside of the N95 mask.

ALERT UVC Light Meter

Not all UV light meters are designed for calibrated measurements of UV-C radiation. Some UV meters exist that measure 254 nm but are optimized for the UV-A and UV-B ranges. When choosing the light meter to use for this project, be certain that it is attenuated around 254 nm for accurate UV-C radiation measurements.

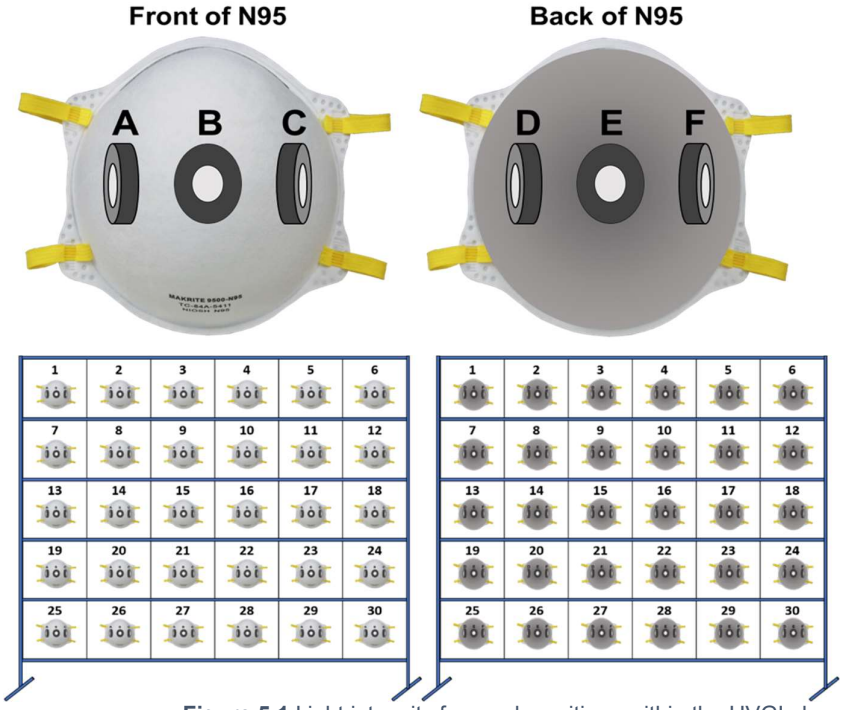


Figure 5.1 Light intensity for mask positions within the UVGI chamber.

To determine the time needed to reach the 1 J dosage this system is designed for, divide the 1 J by the lowest measured value acquired from the UVC light meter. For example, if the lowest measured value was taken at position 29 D and was 536 µW/cm^2, the time needed to reach a 1J dosage would be:

$$\frac{(1 \times 10^6)\frac{\mu W \times sec}{cm^2}}{536\ \frac{\mu W}{cm^2}} = 1865\ sec = 31\ minutes$$

Healthcare Professional Use Instructions

Directions and images within this section marked with an asterisk (*) are taken with permission from the University of Nebraska Medical Center's report on UVGI for N95 Filtering[3].

These instructions represent generic guidelines and will need to be customized for a specific location's resources and guidelines.

- Retrieve a new N95 respirator from a storage location.
- Using a permanent marker, write identification information on front of respirator including the first initial and last name, department location, and date of first use.* See Figure 6.1.

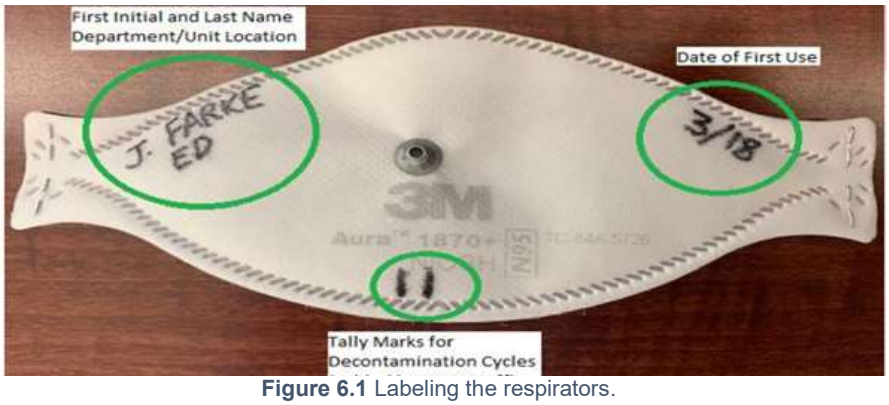


Figure 6.1 Labeling the respirators.
Photo by: Nebraska Medicine N95 Filtering Facemask Respirator Ultraviolet Germicidal Irradiation (UVGI) Process for Decontamination and Reuse[3]

- Upon doffing PPE, place used N95 mask in brown paper bag and ensure the brown bag is correctly labeled with the same identification that is on the mask. *
- Place the brown bag with the used respirator in a designated drop-off location. *

To collect the masks and place them on the mask rack by the designated UVGI associate

A designated UVGI associate will do the following. The associate must don PPE (gown, gloves, and mask) while performing these tasks.

1. While wearing PPE (gown, gloves, and mask), collect the used respirators that have been placed in bags at designated drop-off locations and brings them to the designated UVGI area. * See Figure 6.2.
2. Remove one respirator at a time from each brown bag, and verify a name, location, date, and number of disinfection cycles are present on the respirator.
3. Discard used brown bags in the trash can.*
4. Hang a respirator on four eyehooks, ensuring the mask is taught on the decontamination rack. See, Figure 6.3.

Figure 6.2 Wearing PPE to collect masks from the drop-off location.
Photo by: Nebraska Medicine N95 Filtering Facemask Respirator Ultraviolet Germicidal Irradiation (UVGI) Process for

Figure 6.3 Hanging mask on the four hooks; surgical mask used as an example.

5. Hang all respirators one at a time until the used respirator container is empty. Ensure respirators do not touch one another during this process. See, Figure 6.4.

Figure 6.4 *Masks hung* together *on the rack.*

6. If necessary, replace the reflective material where you entered the area to hang the respirators.
7. Turn off all lights inside the room.
8. Doff gown and gloves at the threshold of the door, exit the room, and shut the door.
9. Perform hand hygiene immediately outside the room and remove your procedural mask.*
10. Turn on the UVC light system's power switch on the power strip or plug the extension cord into the wall outlet.
11. Wait for the recommended time to reach a 1 J/cm^2 dosage. This will need to be determined per UVGI system as explained in the "Testing and Validation" section above.

Figure 6.5 Cleaning the cart and preparing for collecting disinfected masks.
Photo by: Nebraska Medicine N95 Filtering Facemask Respirator Ultraviolet Germicidal Irradiation (UVGI) Process for Decontamination and Reuse[3]

12. While the cycle runs, thoroughly clean the cart and containers used to transport the used respirators. Write names on a new brown bag and place it in a corresponding labeled white bag.* See, Figure 6.5.
13. Once the recommended time of UVGI treatment has elapsed, turn off the power switch on the power strip or unplug the extension cord into the wall outlet.

To retrieve masks after the sanitation cycle is complete

1. Don gloves and procedural mask only and enter the designated UVGI room.
2. Remove the aluminum foil sheets covering the front side of the UVGI system or open the door panels. Collect respirators from the PVC frame, one mask at a time, and place a tally mark on each respirator to record the decontamination cycle.

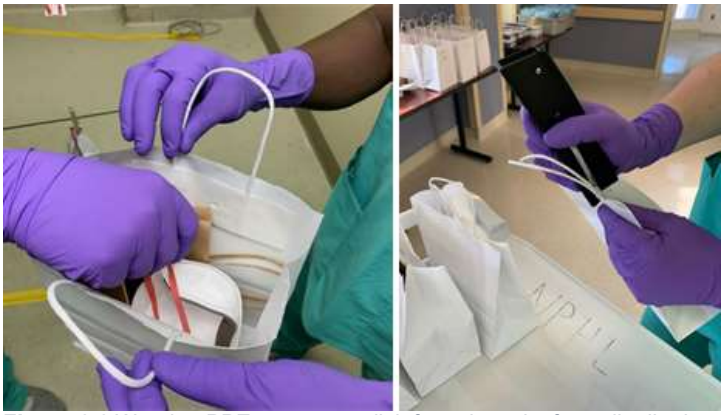


Figure 6.6 Wearing PPE to prepare disinfected masks for redistribution.
Photo by: Nebraska Medicine N95 Filtering Facemask Respirator Ultraviolet Germicidal Irradiation (UVGI) Process for Decontamination and Reuse3

3. Place the respirators into a new white bag, labeling the owner and return location on the exterior of the container. Staple white bag shut. * See, Figure 6.6.
4. Repeat this step until all respirators are removed.
5. Place stapled bags with decontaminated respirators in totes* See, Figure 6.7.

Figure 6.7 Placing stapled bags into the distribution totes.
Photo by: Nebraska Medicine N95 Filtering Facemask Respirator Ultraviolet Germicidal Irradiation (UVGI) Process for Decontamination and Reuse[3]

6. Transfer the decontaminated respirators to their appropriate pick up location. * See, Figure 6.8.

Figure 6.8 Distributing totes of disinfected masks to pick up locations.
Photo by: Nebraska Medicine N95 Filtering Facemask Respirator Ultraviolet Germicidal Irradiation (UVGI) Process for Decontamination and Reuse[3]

7. Return clean cart to drop-off area.

References

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