UV Face Mask Sanitizing Box

University of Idaho

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Version 1.1

Preface

This document provides instructions for building a box with readily available material to hold UV lamps that can sanitize medical face masks for reuse. This is especially important during the COVID-19 Pandemic when personal protection equipment (PPE) is in short supply. Reuse of masks is normally not recommended, but mask sanitization is much safer than mask storage/reuse without sanitization.

UV-C radiation (at 254 nm) has been shown to kill bacteria and viruses, including the COVID-19 virus. A dose of $1 J/cm^2$ is shown to be adequate to deactivate influenza virus in a 2019 report commissioned by the United States Food and Drug Administration, and a similar design has been employed for decontamination of N95s at the University of Nebraska. As influenza and coronaviruses are similar single-stranded RNA viruses, we extrapolated the needed energy requirements from the cited report above to design our unit. This technique for decontamination has also been tested and found adequate in work done by Smith et al. [1] with SARS-CoV-2 virus. The lamps used in our first prototype were spare replacements intended for use at wastewater treatment facilities. Many wastewater treatment facilities use UV lamps to sterilize water before wastewater is discharged to the environment. Specifications of these lamps may vary. Our design was tested with a UV Radiometer and the desired dosage of $1 J/cm^2$ can be accomplished on the order of 17 minutes.

The University of Idaho, in accordance with Governor Brad Little's March 13, 2020 emergency declaration related to the COVID-19 pandemic and his March 25, 2020 declaration of Extreme Emergency, is doing what it can to help the State of Idaho respond to the COVID-19 pandemic. As such, the University of Idaho is deployed its expertise and resources to provide this emergency equipment. While we are building this equipment from designs intended to comply with relevant research and standards, this equipment has not been tested or approved by any third-party testing agency.

Thanks to a donation from the City of Clarkston, Washington, and our partnership with the city of Lewiston, Idaho, we have a limited supply of UV lamps to provide for facilities most needing them. Please contact us to request lamps or for additional information.

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SAFETY: UV Hazard

UV radiation exposure even for short duration can be harmful. Exposure to UVC and UVB results in sunburn and pigmentation. Eye exposure to UVC can result in “flash burn” type injury to cornea. Long term exposure can result in skin cancer and premature aging.

To guard against injury, basic safety precautions should be observed, including the following:

- Never look directly at the light while in operation. For building and testing box, precautions similar to those used in arc-welding should be followed including use of UV-protective gloves, long sleeves, eyewear / welding shield. We recommend no uncovered skin nor uncovered eyes during design, production, or testing of this device while UVC bulbs are in operation.
- Use only as specified by the operating instructions.
- Do not use this equipment for anything other than disinfecting surgical or N95 masks.
- Do not touch surfaces that become hot during operation, including bulbs and inside of chamber.
- Do not use this product in the presence of flammable or combustible materials.
- Ensure that the power button is easily accessible during use.
- If liquid is spilled inside the unit, disconnect it from the power supply and have it checked by a competent person. Ensure the unit is not wet before connecting it to the power supply.
- It is the user’s responsibility to carry out the appropriate decontamination if hazardous material is spilled on or inside the equipment.
- It is the user’s responsibility not to use decontamination or cleaning agents that could cause a hazard due to reaction with the equipment or material contained in it.

Caution: UV Radiation Hazard. Use only with shielding in place. Protect eyes and skin from exposure to UV light.

SAFETY: Fire Hazard

The lamp acts as the heat source inside the box at the same wattage as bulb rating. The heat generated inside the box must be equal to heat dissipated for steady state operation. We do not assume any forced convection and assume that box is placed on an insulated surface.

After continuous use, the average temperature of the box is expected to be at or below 40 °C (104°F) for an ambient temperature is 20 °C (68°F). See appendix C for more information. This is assuming 130W of UV lamps inside the standard box. Smaller box with same wattage will have slightly higher temperature. In any case, **DO NOT COVER THE UNIT**. Operate the unit at well ventilated area.

Caution: Surfaces can become hot during use, including inside of chamber and bulbs themselves.

SAFETY: Ozone Formation from UV

Some UV lamps may produce Ozone. While ozone helps with disinfection, human exposure to higher level of Ozone is not considered healthy. One source (Oxidationtech.com) reports that

- UV light wavelengths shorter than 240 nm will create ozone via photolysis of the oxygen molecule.

- UV light wavelengths between 240-280 nm will destroy ozone via photolysis of the ozone molecule.

- UV light wavelengths between 280-315 nm are mostly absorbed by the ozone layer itself.

Ozone in air, fortunately, is unstable molecule and will convert to oxygen over time. The conversion rate depends on factors such as airflow, temperature, and humidity. Increased level of air flow, temperature and humidity will help lower ozone level rapidly [2]. As safety precaution, we recommend placing the unit in well ventilated area and leave the box alone after completion of UV radiation, for as long as it is practical. If used indoors, United States OSHA guidelines recommends a threshold of no more than 0.1 ppm ozone exposure for up to 8 hours of light work, and no more than 0.2 ppm for no greater than 2 hours exposure [3]. If these amounts ozone are exceeded by detection with an ozone sensor, the box may need to be deployed outdoors for greater ventilation and reduction of human exposure. Of note, some commercially available UVC bulbs are “doped” low-ozone bulbs, and we recommend checking with the manufacturer of bulbs prior to purchase to determine what might best suit your needs.

Ozone Test Results

We tested the Ozone inside the box using MQ-131 Ozone sensor[i] on a 20-minute run. The sensor was reading ambient air ozone level at 10 ppb. When the UV lamp turned on, the reading increasing up to 383 ppb (Parts Per Billion). Rounding up, this is about 0.4 ppm (Parts Per Million) at the end of 20-minute cycle. The initial ozone increase rate was higher, and the increase rate slowed down as time passed. The ozone level was still increasing at about 4 ppb/min after 20 minutes. After the lamp turned off, the ozone level started to decrease at about 1 ppb per minute.

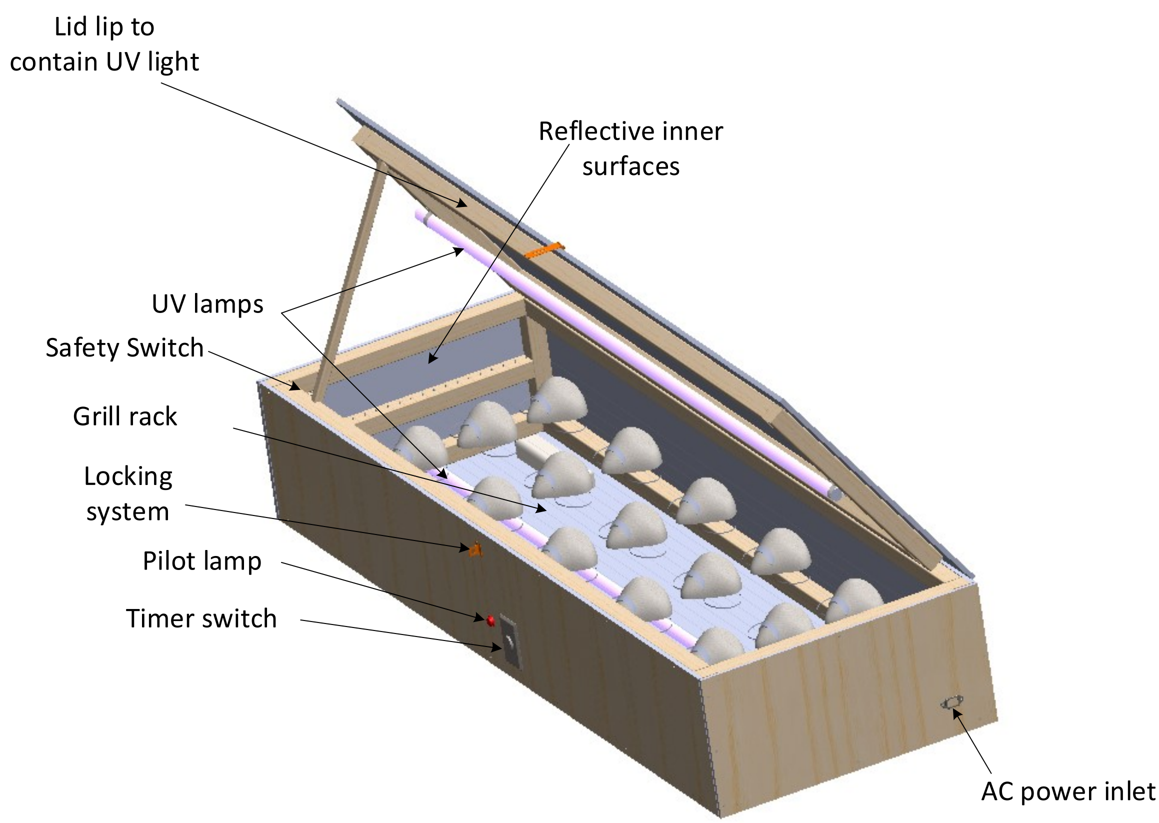
The test shows that there is indeed some ozone being generated inside the box. OSHA limits ozone exposure to short term limit (STL) for 300 ppb. Therefore, we strongly recommend taking precautions, such as placing box in well ventilated area, leaving box unopened after treatment for as long as practical. Other measure such as opening the box, leaving the site and returning to collect the masks after a short while may also reduce the ozone exposure.

[i] https://shop.controleverything.com/products/ozone-gas-sensor-12-bit

Design Features

The sterilization box shown in figure below has the following features when it is built to specification.

1. UV lamps selected to sanitize masks in 10 to 30 minutes.
2. Grill rack in the middle to radiate from top and bottom.
3. Safety switch to turn off UV lamps for accidental lid opening.
4. Timer switch to control radiation timing: 30 minutes
5. Pilot lamp to indicate if UV is ON.
6. Inside surface is made reflective using aluminum tape or glued aluminum foil.
7. The lid has 3/4” lip around to prevent UV light from escaping when closed.
8. Locking system to keep away from unauthorized use.
9. The usable surface area of the unit is about 10 square feet (68” ft x 22”). It can hold about 50 marks in a batch of 5” x 5”.



A short assembly video is available at: https://youtu.be/p6T_c0V7Mhk

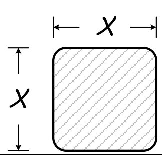
Box Sizing

This box is designed to fit a 61” long UV lamp that is enclosed in 67” long quartz tube used in wastewater treatment facility. The finished box is 71 ½ “wide, 24” deep and 12” high.

For other types of UV lamp, and for other sizes of dimension lumber and plywood thicknesses, the box dimensions may be altered. This dimension can be changed for any width (W), depth(D), and height (H), dimensions as desired. The cutting instructions are given in W, D and H. The amount of plywood, lumber and aluminum foil will vary depending on the box size.

Measure the length and diameter of the UV light bulb (Measure the quartz tube if the light bulb is encased inside quartz tube). The standard box that is described in this document assumes that the UV lamp is 67” long, using 3/8” CDX plywood, and using 2”x2” dimension lumber. If this assumption is correct proceed as instructed for a standard box. The finished box will have an external dimension of 71½”x24”x12”.

For any other sizes, note the following dimensions:

Feature	**Dimension (inch)**	**Recommendation**
Desired box width	W = _______	Box width W = (Tube length + 4 ½)”. Standard width is 71½”.
Desired box depth	D = _______	D = 18” to 24”. Standard 24”. Adjust for available rack size to place masks.
Desired box height	H = _______	H = 12” to 16”. Standard 12”. Could be higher.
Plywood thickness	T = _______	T = ⅜” CDX board. May also use ⅛” tempered hard board.
Actual lumber x-section 	X = _______	2x2 dimension lumber. X = 1½”

Radiation Intensity Calculations

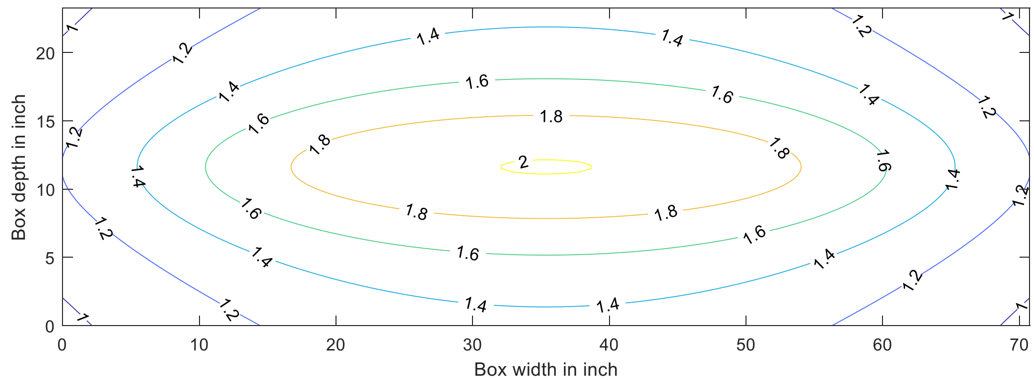


Figure 1: Calculated radiation intensity in mW/cm^2 inside the box with aluminum foil lined box. A bulb above and below design put this amount of radiation from above and below. Actual radiation may be higher.

Calculated radiation intensity distribution from a single 65 W UVC lamp tube (with assumption that 50% of the radiation rated wattage in UVC range) placed 5” above the rack along the box width is shown in Figure 1. If two bulbs are used, one on top and another below, an equal amount of radiation will be applied from underside as well. It was assumed that the box interior is lined with shiny side of aluminum foil. Details of this calculation is given in Appendix B. Based on the recommendation from N95 filtering facepiece respirator decontamination>1J/cm^2 is recommended [4]. To ensure this amount of radiation we take the lowest radiation of 1 mW/cm2. With this radiation intensity it will take at least 17 min (=1000/1 s) get 1 J/cm^2. Therefore, **radiation for 17 min or higher is recommended to deactivate SARS-CoV-2 virus.**

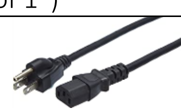
UV Test Results

The radiation measurements were made using a UVC Irradiance Meter (Extech SDL470[ii]). The sensor was placed at the rightmost 1.6 mW/cm^2 contour line in Figure 1. The recorded radiation initially increased from about 0.9 mW/cm^2 to about 1.95 mW/cm^2 in a matter of a minute. Then it stabilized there for about 5 minutes and slowly decreased to about 1.6 mW/cm^2 at the end of the 20-minute cycle. This measurement shows that the above radiation calculations were conservative estimations and were close to measured values. The radiation intensity shown in figure 1 will proportionally change with lamp power. For different shapes of lamp and reflective surface, you may use the Matlab code provided in Appendix B.

[ii] http://www.extech.com/products/SDL470

Parts List

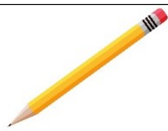
Most supplies should be available at local hardware stores or through online stores.

Supply	DESCRIPTION	QTY.
⅜” Plywood	4’ x 8’	2
2x2 Dimension Lumber	10’ long **OR** 8’long	6 7
Hasp 	1" width	1
Timer switch 	30 min	1
Hinge 	4"	2
Wood Screw 	1 inch	120
Wood Screw 	2 inch	20
Flat head machine screw 	6-32 – 1”	10
Nuts and small washer 	6-32 nut #10 flat washer	10 10
Limit Switch 	Rated for 120V or higher 3A or higher	1
Pilot lamp (red color preferred) 	120V rated	1
Aluminum foil roll 	> 40 sq. ft	1
¾” Pipe Stap (¾” pipe has O.D. of 1”) 		4
Computer Power cord 	15 amp rated	1
AC power entry module Preferably with a switch 		1

Other Supplies

UVC lamp tube w/out quartz sheath and Ballast (Some available on request to ship, please contact us) any UVC lamp about 50W range with 254nm wavelength should work)	65W	2
18-gauge stranded wire 	20’	
PIDG type wire connector 		8
Wire nuts 		6
Electrical tape 		1
38 AWG nichrome wire or Fishing line 	140’	1

Tools Needed

Pencil 	 1/8” drill bit
 Wood saw	Electric drill 
Philip head screwdriver. 	Wire cutter / crimping tool 
½” hole saw 	 Hot glue gun

Fabrication Procedure

Making the Boards

1. Cut from 4’ x 8’ plywood board as shown below.

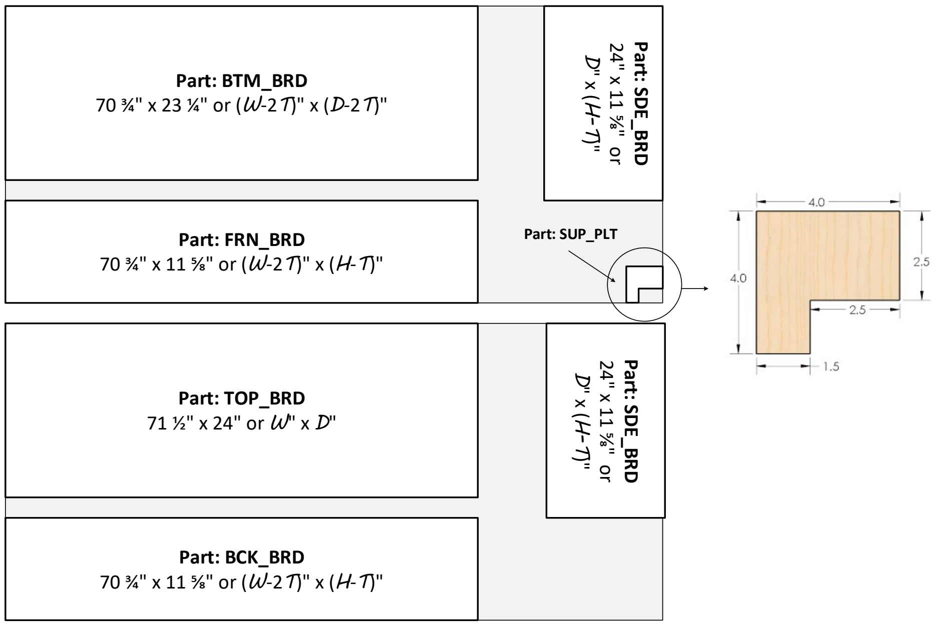


Figure 2: Two 4x8 plywood (T=3/8”) is cut as shown. Standard box has W= 71 ½”, D=24”, H = 12”. Depending on box size adjust the needed plywood.

2. Cut the holes for the pilot lamp and timer switch box on the FRN_BRD (See figure 2 for reference). And hole for AC power Entry Module on one of the SDE_BRD as shown below. For rectangular cuts it may be easier to use 0.5” hole saw first then use regular saw to make the hole rectangular. Adjust the hole sizes for the timer switch and pilot lamp size at hand. The recommended location below ensures that the wires on the back will be below the rack (for safety). For AC power Entry Module, make the hole on the side most convenient to connect to the power outlet.

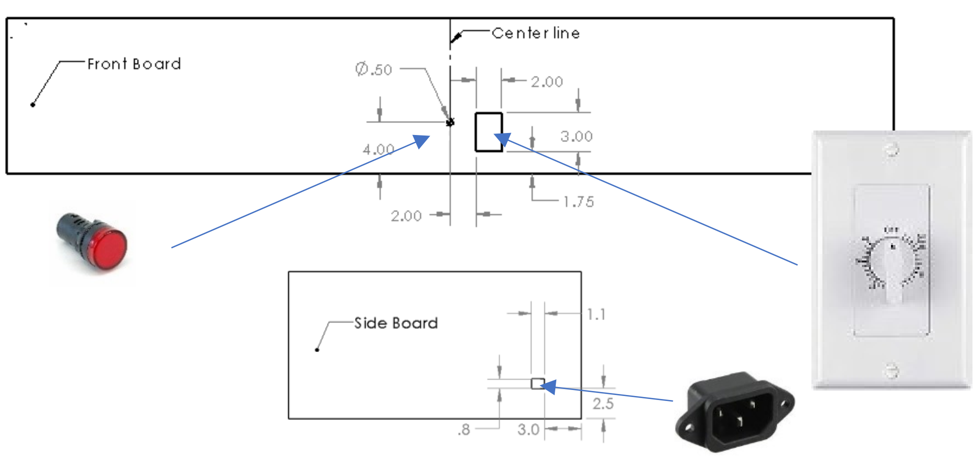


Figure 3: Front Board. The circular hole is for pilot lamp and rectangle hole is for timer switch. Adjust the hole sizes for parts at hand.

3. Glue aluminum foil on one side of each plywood panel. Feel free to use a combination of aluminum foil with hot glue or aluminum tape. Set the panels aside for later use.

Building the Frame

4. Cut Six pieces of 10 ft long dimension lumber into pieces as shown. For 8’ long lumber gets two BOX_V, two Box_M and SCRAP wood from the 7th piece.

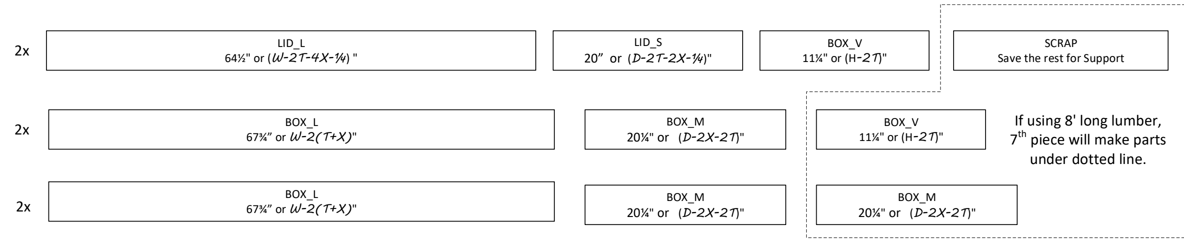


Figure 4: Six 10' long 2x2 lumber is cut as shown. Use precalculated lengths as shown for the standard box or calculate your own for different sized boxes. Save longest scrap woods of about 2’ for lid support. Mark part names as shown on wood with a pencil.

5. **Put screws on the middle bar**: *This step is needed only if the middle rack is built from nichrome wire or fishing line. If metal rack is available of appropriate size, change the design to hold the rack in place*. Take two pieces of BOX_M part from Figure 4. Pre-drill small pilot holes at 0.25” from side and are 1” apart as shown below and fasten 1” inch screws. Please make a note that the screws are not driven all the way in. This is to tie the wire to make a mask rack. The spacing between screws can be adjusted depending on the size of the object that is being sanitized.

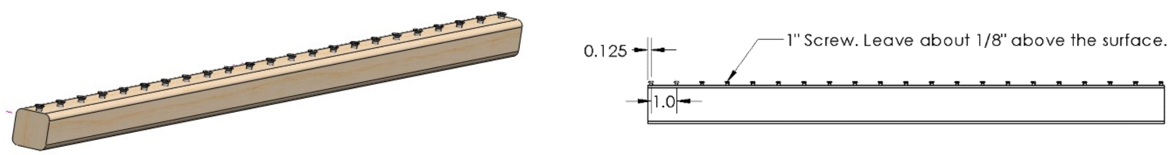


Figure 5: The middle bar (Part: BOX_M) provides a way to make middle rack using fishline. Fishlines are tied to the small protruded screw heads.

6. **Build SIDE FRAMES:** Take the middle rack you built in the last step. Take two BOX_V and the two BOX_M parts from Figure 4 to create a side rack like below. Use six 2” screws from side to secure. Make two units of this assembly.

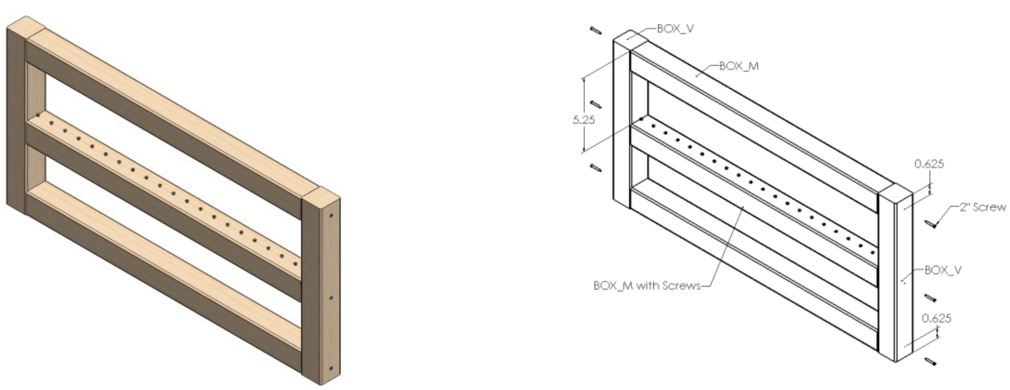


Figure 6: Build two SIDE FRAMES like this one

7. **Complete the frame**: Add four BOX_L parts as shown below to SIDE FRAMES from the last step. Use 2-inch screws from sides to complete the frame.

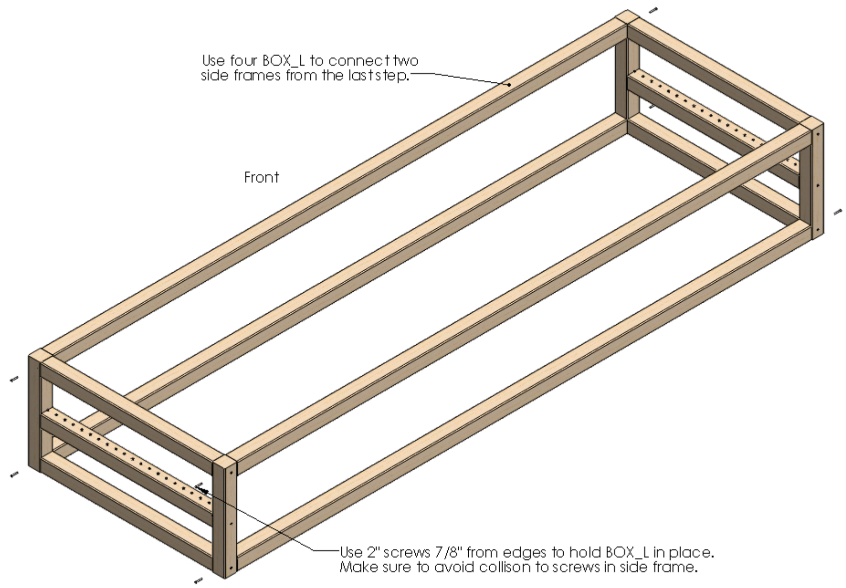


Figure 7: Complete building the frame.

Placing Components Together

8. Make two pilot holes with 1/8" drill bit as shown on a SUP_PLT (from figure 2) . Each hole is ¾" from adjacent edges. Then secure a limit switch using 6-32 machine screw, nut and washer as shown below. The limit switch is placed so that top of micro switch aligned with top of the support plate.

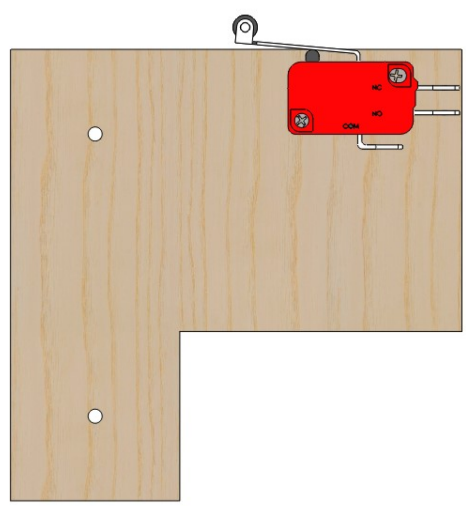


Figure 8: Support plate (SUP_PLT) and limit switch assembly

9. Secure support plate assembly from the last step as shown below. Use ½" screws to secure in place. The supports should be flush on outside frame as shown below.

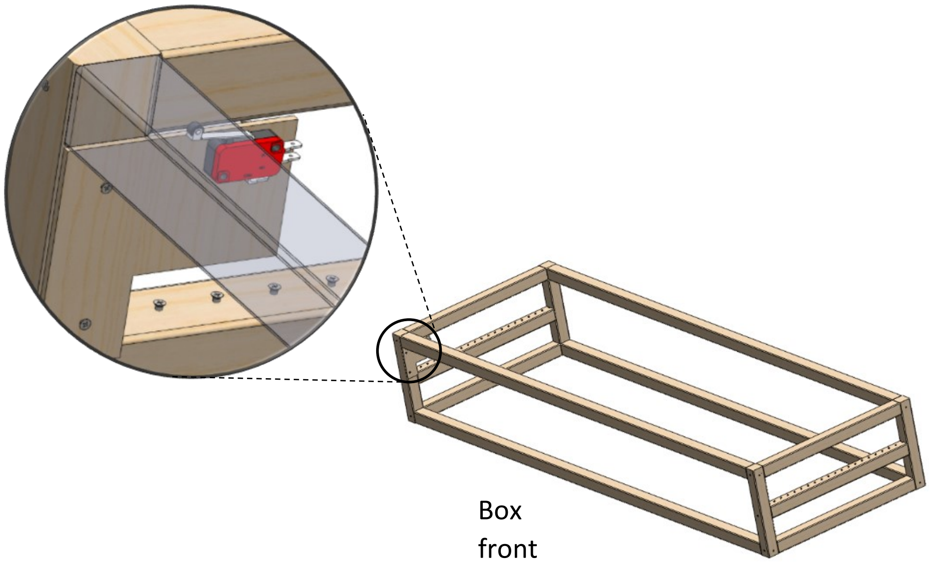


Figure 9: Support plate assembly from last step is attached to the frame

10. Flip the frame upside down then place the bottom board so that aluminum foiled surface is facing inside. Secure the board with 1” screws. Evenly space screws in long side (6” from side and then about 12” apart”) and two screws in short side.

Figure 10: Flip the frame and screw the bottom panel with shiny side inside

11. Flip the frame back to straight up. Screw front and back panel in the same manner as the bottom panel with aluminum foiled surface inside. The panel should be flush with frame all around.

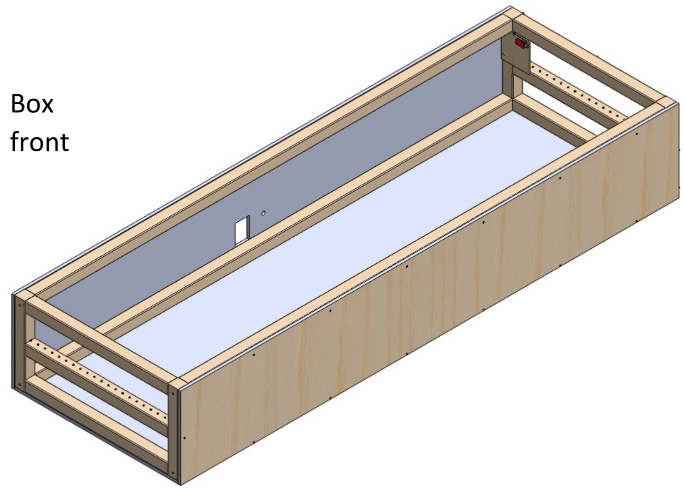


Figure 11: Attach front and back panel with shiny side inside. CAUTION: Avoid screwing into inner screws.

12. Add side panels. Evenly space two screws on each side.

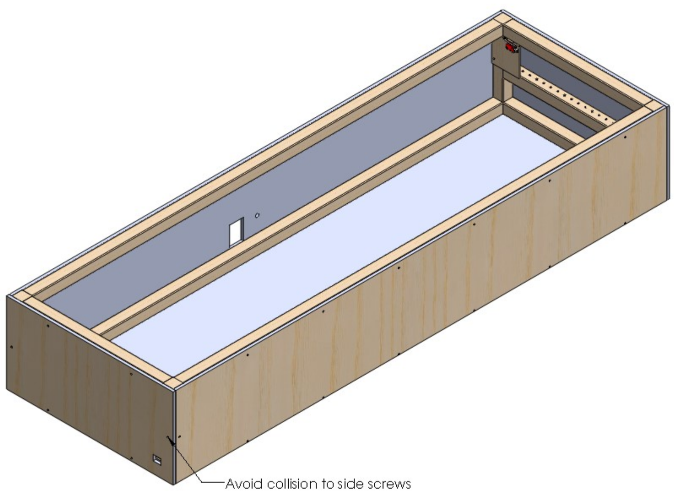


Figure 12: Attach side panels with shiny side inside. When screwing in make sure to avoid collision to side screws.

13. Secure pilot lamp and timer switch as shown below in front board. Secure AC power Entry module on the side panel

Figure 13: Secure pilot lamp and timer switch on front panel, AC power entry model on side panel

14. Secure UV tube as shown below at the bottom using pipe strap. Also secure the ballast on a side. Use 6-32 machine screw, washer and nuts as needed.

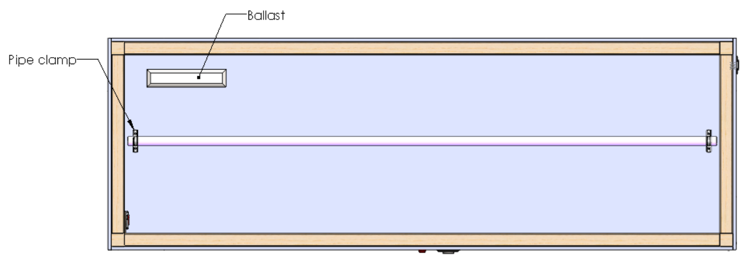


Figure 14: Secure Tube and Ballast. UV lamp is clamped down using pipe strap at ends..

Building the Lid

15. **Building the lid**: Lay down four two LID_S and two LID_L lumbers as follows:

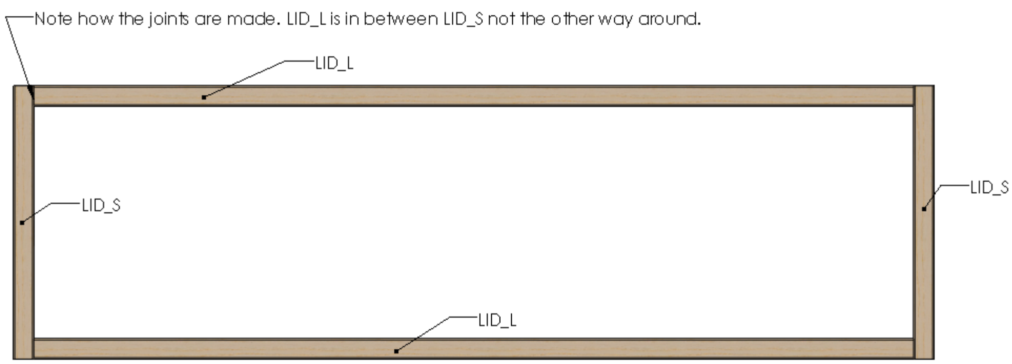


Figure 15: Lay down lumbers on a flat surface as shown. See Figure 5 for part reference.

16. Carefully place the top board on top of centered. If centered, the board should hang 2" in all four direction. Make sure not to stir the lumber underneath when placing the board.

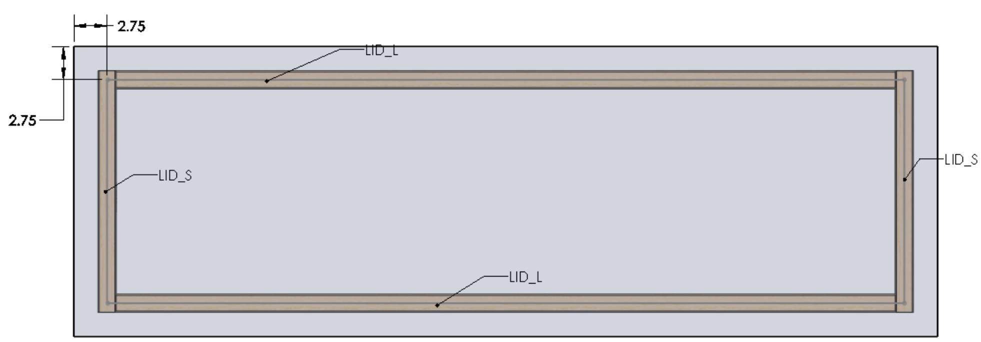


Figure 16: Carefully place the top board on top of laid lumbers making sure they don't move. If centered, the board should hang 2" in all four direction.

Make a pencil mark 2.75 (2¾") around the border. Fasten 1" screw on the mark at about 12" apart.

17. Flip the lid. Clamp on another UVC lamp tube as shown below.

Figure 17: Using pipe strap, clamp another UV lamp to the center of the lid as shown below

Securing the Lid

18. Place the lid on top of the box.

Figure 18: Place lid on top.

19. Screw in the hinges and hasp. Hinge distance from one another should be around ½ of the box width and be symmetrical. Hasp is placed at the middle of the width. Place hasp eye to match.

Figure 19: Secure hinges and hasp

Electrical Wiring Diagram

20. Connect the circuit inside the box using 18-gauge stranded wire. Any solid wire, such as many ballasts are prewired with, cannot withstand repeated bending between the lid and the body of the

box. Connect ground neutral and line in the following diagram to the AC Power Entry Module. The module will have marking for Line (L), Neutral (N) and Ground (⏚). Use white wire for neutral, black for live green for ground. Put electrical tape around any exposed conductors. Avoid any exposed wire to touch aluminum foil except for ground wire. Use PIDG wire connector to connect components as needed.

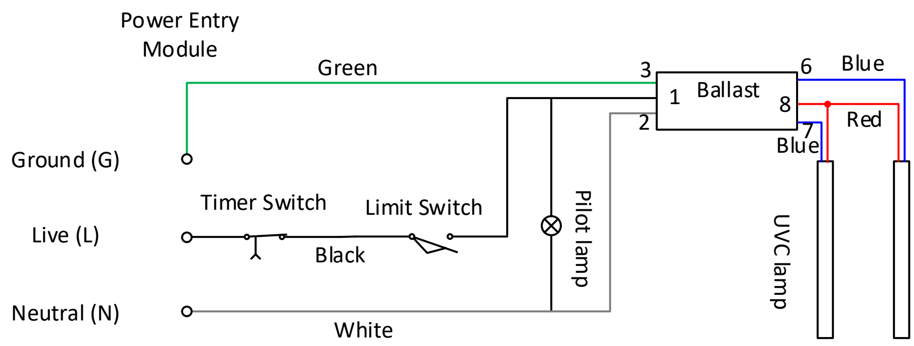


Figure 20: Electrical connection diagram from power entry module

21. To connect the limit switch, use 18 gauge about 6’ black wire and PIDG connector for common (usually marked COM) terminal of the limit switch and black colored wire to NO (Normally Open) terminal of the switch. Leave the Normally Closed (NC) terminal unconnected. Use electrical tape to cover any exposed terminal or connection for safety.

22. Wires coming out of ballast are also color-coded. Connect terminal 6 and 7 (blue wires) to one side of lamp, connect terminal 8 (red wire) to other side of ballast and twist them together as shown in figure 19. Connect terminal 2 (White wire) to neutral, connect terminal 3 (Green wire to Ground), and Connect terminal 1 (black wire) to in series with timer and limit switch following Figure 20.

23. Connect the pilot lamp in parallel to terminal 1 (Black) and 2 (White) of the ballast.

Finishing up

24. Once everything is secured. Use 38 AWG Nichrome wire or fishing lines across the middle rack to build the platform to place the mask. One simple loop to keep equal distance between wires is shown below. The unit is now ready to use.

Figure 21. A simple loop that will keep the wires at equal distance. Wires are proportionately shown bigger for clarity.

25. Take the spare 24” long 2x2 wood from Figure 4 and make a notch on both ends. Use this scrap wood to keep the lid propped open while loading or unloading mask.

Figure 22: Use the scrap wood from figure 4 to make a prop to hold the lid.

26. Connect the power cable to AC Power Entry Module.

27. Print and stick the “OPERATING PROCEDURE” from Appendix A on top of box lid.

28. Connect the Power cord to a regular 120V household power supply.

29. Load the mask on the rack and follow the operating procedure to operate the unit.

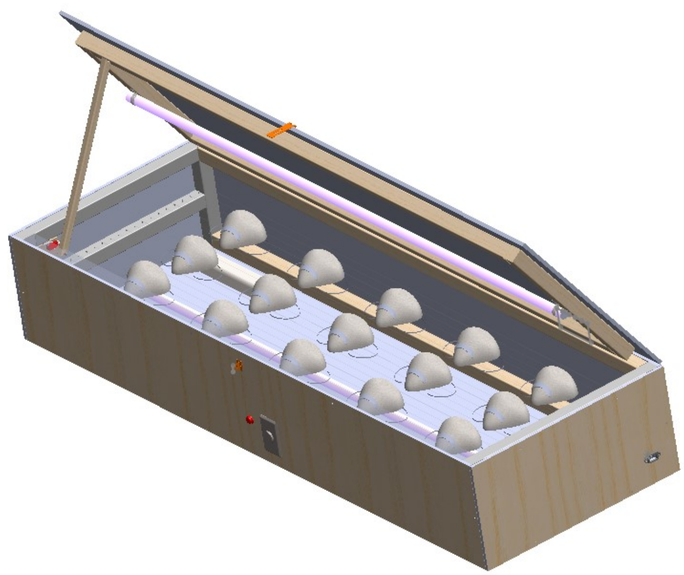


Figure 23: Finished box loaded with masks.

In order to make sure UV lights turn on, we recommend using a power meter (such as kill-a-watt meter available readily from many vendors like Amazon.com) to measure power input. Alternatively, small pilot holes (1/8” of less) can be drilled and sealed with hot glue to leak some light on a wall or other surfaces.

We do not recommend overriding manually depressing limit to test if lamp turns on. This will expose a human to UV light, we recommend reducing human exposure to UV light as much as possible. AVOID LOOKING DIRECTLY INTO UV LIGHT!

Appendix A

Print and stick the following operating procedure on the lid:

OPERATING PROCEDURE

UV Light hazard, Device must be de-energized before opening the doors and should only be energized after doors are securely closed. UV-C radiation is dangerous if exposed to skin or eyes. Use extreme caution while operating.

Make sure to place the device in a well-ventilated area with air flow to provide escape for the Ozone gas generated.

1. Plug the device in to a 120 V AC outlet.
2. Place the masks on the shelf making sure they are not overlapped.
3. Close the lid. Opening the lid any time will immediately disconnect the power.
4. Turn the timer knob to the appropriate time (17 min recommended for $1J/cm^2$ radiation). After the time elapses, the UVC sterilization process is complete. Carefully remove the masks and collect them for reuse.

Caution: UV Radiation Hazard. Use only with shielding in place. Protect eyes and skin from exposure to UV light.

Caution: Surfaces can become hot during use, including inside of chamber and bulbs themselves.

Appendix B: Calculation of UV Radiation on the Rack

This is an analysis to determine the UV radiation intensity at various locations for a given configuration. Figure 21 shows the top side views of the box with lamp. The right-hand front corner of the mask rack has coordinate (0,0,0). Is it assumed that the rack is full of mask and no light passes through the rack.

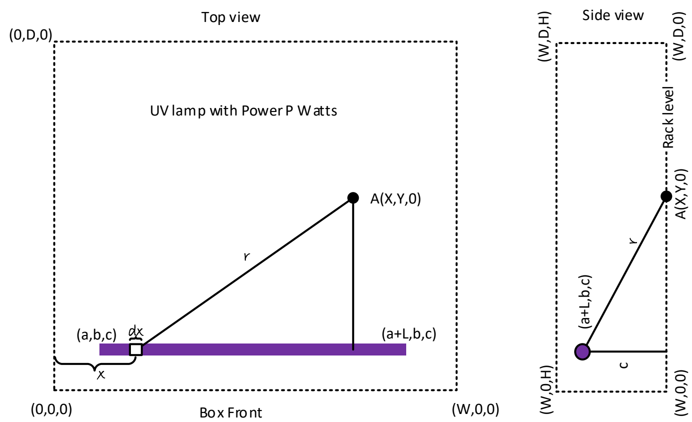


Figure 24: Viewing the box from top. The lamp is assumed to have uniform intensity along the tube. Light length = L.

Lighting intensity in of the lamp $(\rho) = \frac{P}{L}$ Watt/m, where P is rated watt for UV and L is lamp length.

Light falling on point P from a small length (dx) of light $(di) = \frac{\rho\, dx}{4\pi r^2} = \frac{P\, dx}{4\pi L\, r^2}$ Watt/m^2. This equation assumes that a point light radiates uniformly in all direction.

First, we will calculate the UV intensity just from the lamp with no reflection. The light intensity (i) on the top surface at any point (X,Y,0) at distance r is given by

$$i = \int di = \int_a^{a+L} \frac{P}{4\pi L} \frac{1}{r^2} dx \tag{1}$$

But from geometry in figure 21, $r^2 = (X-x)^2 + (Y-b)^2 + c^2$. Since b and c are constants for a given lamp location, we can write,

$$r^2 = (X-x)^2 + k^2 \tag{2}$$

where $k^2 = (Y-b)^2 + c^2$. Combining equation 1 and 2, we get,

$$i = \int_a^{a+L} \frac{P}{4\pi L} \frac{1}{(X-x)^2 + k^2} dx, \tag{3}$$

$$i = \frac{P}{4\pi L} \left[\frac{-\tan^{-1}\left(\frac{X-x}{\sqrt{k}}\right)}{\sqrt{k}} \right]_a^{a+L}$$

$$i = \frac{P}{4\pi L\sqrt{k}} \left\{ \tan^{-1}\left(\frac{X-a}{\sqrt{k}}\right) + \tan^{-1}\left(\frac{a+L-X}{\sqrt{k}}\right) \right\} \tag{4}$$

Equation 4 gives the basis for radiation calculation at any point on the rack. This is from the main lamp without considering reflection from box walls. If we image a box with reflective coating, the point of interest will see reflections of lamp. In the following section we will develop the intensity at a point with reflection from walls.

Radiation Calculation with Reflection

When the box is lined with aluminum foil, the foil acts as a mirror with some reflectivity. The reflectivity of aluminum foil measured by Pozzobon et al. [5] is given below.

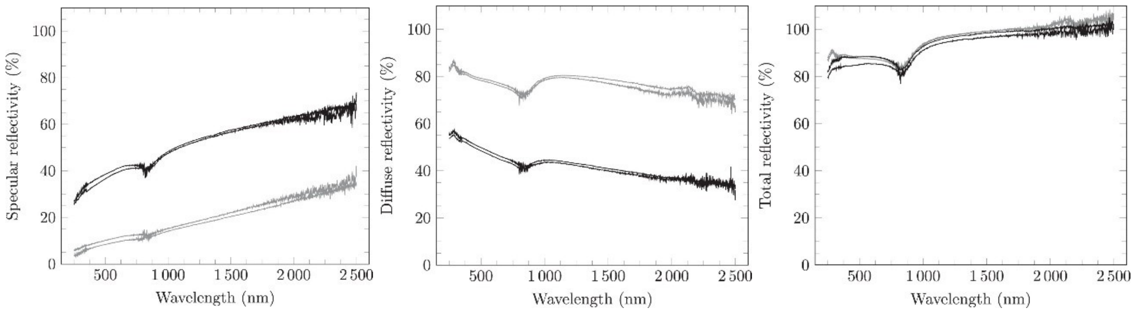


Figure 25. Aluminum foil specular reflectivity, at two different points on each side. Black: bright side, gray: matte side.

At 250 nm range of UCV, the specular reflectivity (R_s) is 25% and Diffuse reflectivity (R_d) is 55% for shiny surface. Specular (mirror-like) reflection occurs when a surface is very smooth. An incident ray of light is reflected by the surface into a single ray of light with the reflection angle being equal to the incident angle. Diffuse reflection, on the other hand, is produced from rough surfaces and from scattering from inside of the reflector material and is characterized by the light being reflected through a broad distribution of angles, even for a single angle of incidence [6].

Specular Reflection

The specular reflection is from mirror images of the main lamp. Although with the parallel mirror, there are many reflections, the image becomes farther and farther. So to keep the estimation simple, we only use the first reflection as shown in figure 23. We can use equation 4 to estimate the intensity at point X,Y from each of these mirror images with specular reflectivity of 0.25. Therefore, the sum of specular reflection is:

Radiation intensity from specular reflection $(i_s) = R_s \sum_{n=1}^{5} i_n$ [5]

Figure 26: Reflection of the UV lamp from aluminum foil. Reflection with only one bounce of UV ray is shown here. Higher order of reflections are neglected.

Diffuse Reflection

When light hits a surface, the surface itself acts as a light source radiating in all direction. Calculating radiation intensity from diffuse light involves the following steps:

1. calculate radiation intensity (i) falling at a point W/m^2.

2. Then multiplying this intensity by small area δA. Now δA act as a radiation source of power $R_d * i * \delta A$.

3. Integrate the radiation falling at point (X, Y) from each of these light sources.

To simplify the calculation, we assume that diffuse reflection falls uniformly in all surface. So diffuse reflection at point X, Y is given by

$$i_d = P * R_d * \frac{Shiny\ area}{Total\ area} * \frac{Rack\ area}{Total\ area} * \frac{1}{Rack\ Area} = P * R_d * \frac{Shiny\ area}{Total\ area^2} \quad [6]$$

Therefore, total radiation on point X, Y is given by

$$i_{total} = i + i_s + i_d \quad [7]$$

Radiation Calculation for the Box

For the box designed in this document, the parameters for equation 4, 5 and 6 are:

Bulb Rated Power = 65 W
Specular Reflectivity = 0.25
Diffusive reflectivity = 0.55
Lamp length in inches = 58
Box width = 71.5
Box Depth = 24
Box height = 12
Is calculated as below:

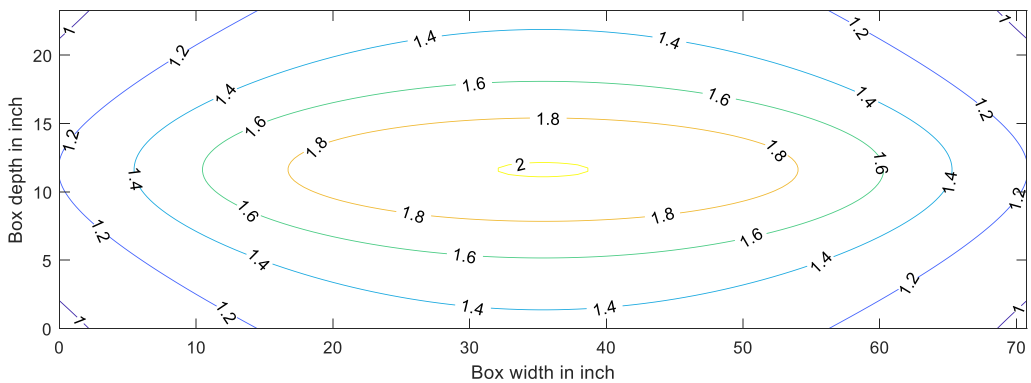


Figure 27. Calculated radiation intensity in mW/cm² inside the box with aluminum foil lined box. A bulb above and below design put this amount of radiation from above and below. Actual radiation may be higher.

A complete Matlab® code to calculate and generate above diagram is given below.

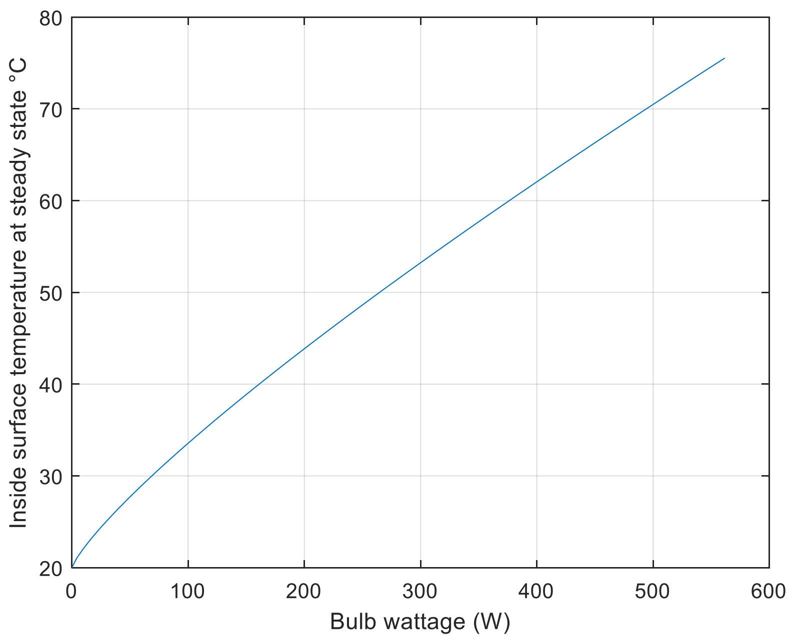
```
P = 65*0.5;                % Lamp power. Assumed 50% of power in UVC range
Rs = 0.25;                 % Specular Reflectivity of the surface
Rd = 0.55;                 % Diffusive reflectivity
L = 58/39.37;              % Lamp length in inches converted to meter
W = (71.5-0.75)/39.37;     % Internal Box width in inches converted to meter
D = (24-0.75)/39.37;       % Internal Box Depth in inches converted to meter
H = (12-0.75)/39.38;       % Internal Box height inches converted to meter

a = (W-L)/2;               % Assuming lamp is centered width wise,
b = D/2;                   % Assuming lamp is centered depth wise,
c = (H/2) - 1/39;          % Assuming lamp is 1" crom the top and the bottmom

%Generate the mesh of x and y coordinates
x = linspace(0,W,100);
y = linspace(0,D,100);
[X,Y] = meshgrid(x,y);

%Main lamp
k = sqrt((Y-b).^2+ c^2);
i = 0.1* P/(4*pi*L) * (atan((X-a)./sqrt(k))+ atan((a+L-X)./sqrt(k))) ./sqrt(k);
% i is multiplied by 0.1 to convert form W/m^2 to mW/cm^2

% Reflection 1 and 2 are only different in b
b1 = -b;
b2 = 2*D-b;
```

```
k = sqrt((Y-b1).^2+ c^2);
i1 = 0.1* P/(4*pi*L) * (atan((X-a)./sqrt(k))+ atan((a+L-X)./sqrt(k))) ./sqrt(k);%in
mW/cm^2
k = sqrt((Y-b2).^2+ c^2);
i2 = 0.1* P/(4*pi*L)*(atan((X-a)./sqrt(k))+ atan((a+L-X)./sqrt(k))) ./sqrt(k);%in
mW/cm^2

% Reflection 3 and 4 are only different in a,
a3 = -(W - a);
a4 = W + a;
k = sqrt((Y-b).^2+ c^2);
i3 = 0.1* P/(4*pi*L) * (atan((X-a3)./sqrt(k))+ atan((a3+L-X)./sqrt(k))) ./sqrt(k);%in
mW/cm^2
i4 = 0.1* P/(4*pi*L) * (atan((X-a4)./sqrt(k))+ atan((a4+L-X)./sqrt(k))) ./sqrt(k);%in
mW/cm^2

% Reflection 5 is only different in c, there is no reflection 6.
c5 = H - c;
k = sqrt((Y-b).^2+ c5^2);
i5 = 0.1* P/(4*pi*L) * (atan((X-a)./sqrt(k))+ atan((a+L-X)./sqrt(k))) ./sqrt(k);%in
mW/cm^2

% Intensity from diffusive reflection

ShinyArea = W*D+H*(W+D);
TotalArea = ShinyArea + W*D;
Id = 0.1*P* ShinyArea/TotalArea^2; %mW/cm^2
% Calculate the total intensity

Total = i + Rs * (i1+i2+i3+i4+i5)+ Rd* Id;
% Make the contour plot. Contour values can be controlled using parameters after
% Total like [C,h]=contour(X*39.37,Y*39.37,Total,[1:0.2:2]); Default is used.

[C,h]=contour(X*39.37,Y*39.37,Total);
clabel(C,h);
xlabel('Box width in inch')
ylabel('Box depth in inch')
axis equal
```

APPENDIX C: Temperature Rise Calculation

The lamp acts as the heat source inside the box at the same wattage as bulb rating. The heat generated inside the box must be equal to heat dissipated for steady-state operation. Assuming there is no forced convection, heat loss from outside is mainly natural convection. Assuming the box is placed on table and hence heat loss from the bottom is negligible. For an ambient temperature is 20 °C (68°F).

A simplified convective heat coefficient that gave the conservative estimation on temperature rise is used for this calculation[7]. Thermal conductivity of plywood is = 0.13 W/m°C [8]. The average inside surface temperature is shown below.



We see that average surface temperature is going to be about 37 °C for 130W bulb.

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