UVGI N95 Mask Sterilization Project [Tanzania]

Room 1 Report

Contents

Background

A reliable supply of Personal Protective Equipment (PPE) is essential for the safety and protection of healthcare workers. Ultra-Violet – C (UVC) sterilization has demonstrated efficacy in the disinfection of N-95 masks- a critical piece of healthcare worker PPE. Using UVC, a single N-95 mask could be reused up to five times. Rice University's Imaging Department developed a low-cost UVC system for rapid deployment in resource limited settings. One sterilization unit has an estimated throughput of ~200 masks in a ~20 min run to allow 2000 masks to be sterilized within 10 runs per day.

In resource-limited hospitals such as Muhimbili National Hospital, the ability to reuse some forms of PPE would have a drastic impact on supply and hence, protection of healthcare workers. Given both Tumaini La Maisha (TLM) and Rice University's commitment to the advancement of international health, the two organizations collaborated on the refinement, construction, validation and testing of a UVGI N95 Mask sterilization system.

Rice 360°'s initial investment into the project allowed for the construction of one room. However, the project was awarded a grant by the Irish Embassy for the construction of at least 6 more rooms. The report presented here details the activities conducted during construction of the first room.

Proposed Timeline & Tasks

Phase	*Activities*	*Responsible Party*	*Deliverables*
Initiation	Select beneficiary hospitals and wards.	TLM & RICE	List of hospital ward with specific primary contact person for each. Written approval from hospital/ward leadership for the construction of the sterilization room
	Identify hospital/ward representative to serve as primary contact and rapporteur for UVC-unit.	TLM	
	Author sterilization room management training module.	TLM & RICE	Two documents, one detailing how wards can integrate the sterilization room into existing protocol and another on how to safely run and manage the UVC N95 sterilization rooms. With approvals from Muhimbili National Hospital and Rice University Imaging Department Representative before continuation.
Procurement & Preparation	Identify appropriate hospital rooms according to given specifications.	RICE	Written verification of each room dimensions as appropriate for the sterilization units from Rice Imaging Department.
	Purchase all locally available supplies.	TLM	All materials purchased, with receipts handed to TLM and warehoused at TLM and the DIT Design Studio.
	Purchase and ship all non-locally available supplies.	RICE	
	Run mathematical model of each suggested room to determine room configuration.	RICE	Written results of mathematical modelling results with room configuration description.
Construction	Room review and installation of electrical fittings by electrician.	RICE	Clean room with external on/off switch and external locks.
	Construct UVC N95 mask sterilization room.	RICE	Fully functional UVC N95 sterilization unit.
Integration	Validate and test each sterilization room.	RICE	Verify room readings using UVC lightmeter and report back readings
	Train at least two (2) hospital staff members on use and management of the sterilization rooms.	RICE	Completion of a short assessment post training to ascertain understanding
	Train hospital ward members on N95 sterilization room protocol.	TLM	One workshop and distribution and posting of educational materials on sterilization protocol to members of the ward.
	Assess adoption of N95 sterilization protocol and safety measures.	TLM	Survey results from sterilization room users and observers.
Documentation	Author report on our process, best practices, and lessons learned, and impact measured.	TLM & RICE	Report shared with all collaborators and funders. One delivered upon the completion of one sterilization room and another upon the completion of the project.
	Publication of blog post/news article on project outcomes.	TLM & RICE	Publication shared with all collaborators and funders upon completion of the project

Needs finding

Given TLM's focus on Pediatric Oncology, a room within the Pediatric Oncology ward was selected for the project. Prior to construction, the DIT Design Studio conducted a needs finding mission to better understand the ward occupants, existing mask disinfection and to assess the room proposed for the system. Findings from these visits are detailed below.

User insights

Interviews were conducted with clinicians, cleaners and engineers working at Muhimbili National Hospital. Individuals interviewed included:

- Dr. Monica Apollo- MNH Head of Pediatrics.
- Daudi Mapunda - PICU Nurse in-charge.
- Dr. Juma Mfinanga - MNH Head of Emergency.
- Eng. Aksante - MNH Head of Biomedical Engineering
- Doctors, nurses and pharmacists in the Pediatric Oncology Department.

From the interviews, we were able to uncover a number of user insights relevant to the construction and further iteration of the system.

There exists a need for and keen interest in UVGI facilities at MNH.
MNH staff members already have experience and are comfortable with reusing face masks.
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1. **There exists a need for and keen interest in UVGI facilities at MNH.**
    - All departments visited were keen to have their own UVGI room. MNH Pediatric Oncology (PO) staff use nearly 70 masks per day. Current hygiene protocol for instruments, cables, and tubing and cloth masks is decontamination with Jik (bleach) in a 3-step protocol. Of the wards we visited, mask autoclaving was only available at PO. An autoclave takes 45 minutes to autoclave 9 masks, hence the need for a tight clinician autoclave use schedule.
2. **MNH staff members already have experience and are comfortable with reusing face masks.**
    - MNH Pediatric Oncology and PICU staff receive 6 N95 masks per month. Each staff member is responsible for the cleaning and sterilization of their own mask. During high COVID-19 alert, staff would wash (soap and water) and then autoclave their masks. Emergency staff receive 3 masks/month. MNH PO Staff members use cloth bags to store and an autoclave to sterilize their masks according to a set schedule.

3. Mask wearing, mask sterilization and mask costs are not a top priority within the hospital.

- Multiple clinicians and most patients within the wards were not wearing masks. During interviews clinicians expressed feeling that Corona high risk times were behind them and had since become lax with wearing and sterilization of masks. The Head of Emergency was not curious if at the current price + volume distributed, rooms would be worth the cost.

4. **Sterilization of medical devices is deemed of higher priority than face masks.**
    - Clinicians at all wards visited insisted that N95 masks were not the most critical object requiring sterilization. Sterilization needs identified most recently were gauze, blood pressure cuffs, medical device cables and tubing, oxygen masks and scrubs.

Construction

Room Evaluation

The proposed room (hereafter referred to as R1) is on the 3rd Floor of the Pediatric Block of Muhimbili National Hospital. The room is along a corridor and has a door that can be fully closed. Location allows for easy access to wards. Room dimensions are detailed below.

Before construction, it was determined that there were a number of challenges accorded by the room:

- Room dimensions were determined to be smaller than is recommended in the manual.
- R1's door opens inwards, which further limits the amount of usable space in the room.
- A shuttered glass window above the R1 door provided opportunity for radiation leakage.
- R1 did not have a power outlet.

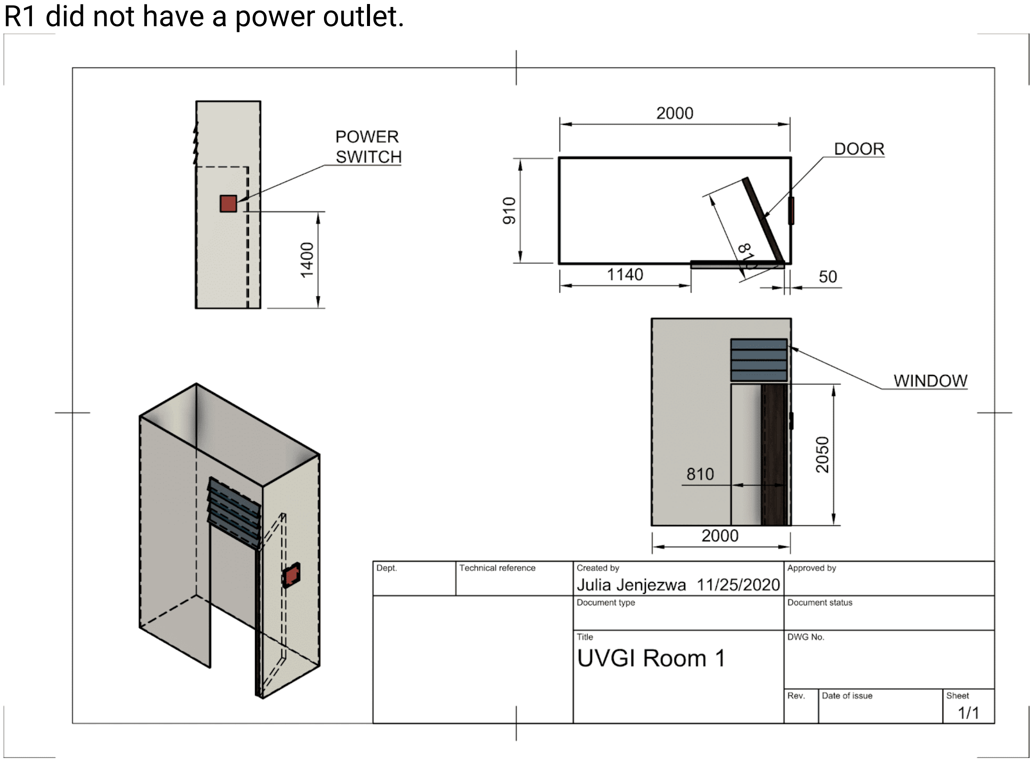


Figure 1 CAD model of R1 showing dimensions and key features

These constrains necessitated a revision of our existing design and additional preparation of the room before construction could begin.

To rectify the challenges detailed above, the DIT Design Studio team:

- Revised calculations to account for a smaller room footprint.
- Attached wheels to the mask holder allowing it to be moved into and out of the room.
- Reduces the size of the mask holder and thus, the number of masks that can be sterilized in one go.
- Designed, lasercut and installed a custom window blocker to prevent UV leakage.
- Rewired R1 to retain the existing light switch, place in an external UV switch and place an internal plug/outlet to power the UV lights. This step was conducted by a skilled electrician who was able to verify that sufficient power was delivered to the system before construction began.

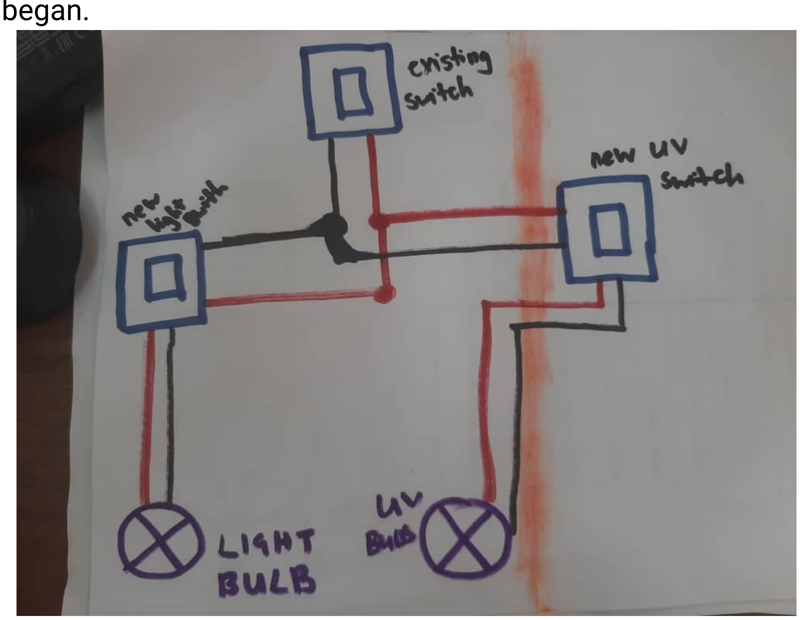


Figure 2 Preliminary draft of rewiring plan

For a detailed explanation of the room revisions, please see our review here.

Construction

Figure 3 DS member and technician working on room construction

Upon completion of the room revisions, the construction of the system began in earnest. The room was constructed according to the requirements in the manual. Save the UV light bulbs, ballasts and connectors – all other materials used to build the system were locally procured.

Construction involved:

- Covering all internal surfaces of R1 in aluminum foil.
- Mounting UVC light bulbs on the wall by the 9hor connectors.
- Wiring the lights to the ballasts and verification of correct connection.
- Wiring ballasts and extensions to the power outlet.
- Picture test to verify correct connections and functionality of the lights.
- Placement of warning signs on the door to deter entry by unauthorized personnel.
- Reconstruction of the mask holder to include Teflon taped connections, PVC screw connections, inner metal rods and additional wheels for greater mobility and rigidity of the structure.

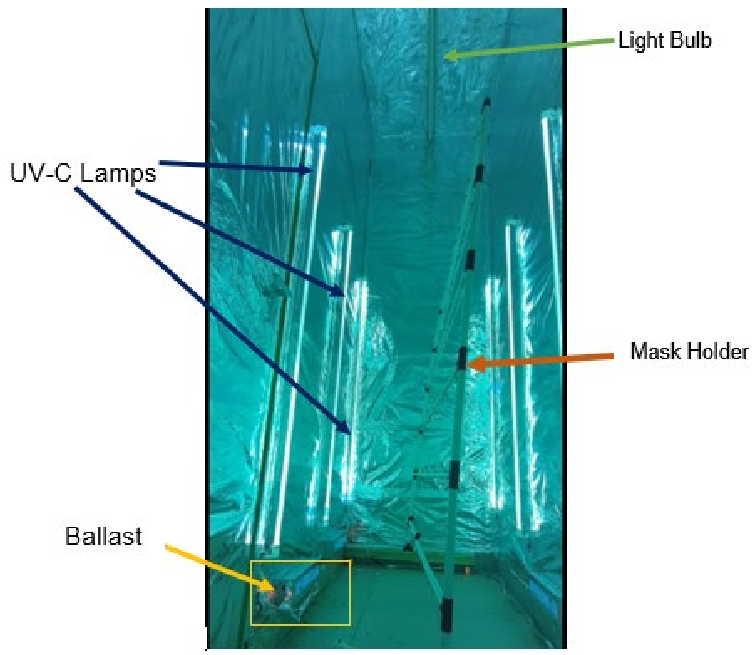


Figure 4 "Picture test" of the UVGI room

During construction there are a number of changes/additions we made according to the needs at our site:

I. Viewing Window

Although most of the shuttered window was blocked with wood and aluminum foil, we included a small window through which the system function can be confirmed after the UV switch is turned on. We ensured that the window was located over a glass covering to prevent UV leakage.

II. Mobile Mask holder (positioning)

Due to limited space within R1, a user cannot comfortable move into and out of the room to place/remove mask. Thus, it was decided that the mask holder would be mobile. We achieved this by placing rotating wheels on the base of the mask holder design.

III. Number of masks

Due to the small room dimensions and door swing direction, only a 4x5 mask holder fit properly into the room.

IV. Lightmeter holder

Our validation experimentation required that the UV lightmeter sensor be held in position for the duration of the experiment for data collection. To ensure this, we designed and fabricated a custom lightmeter holder that allowed for the UV lightmeter sensor to be fixed in a specific position and facing a fixed direction.

Figure 5 the UV lightmeter holder

V. Mask holder reinforcement

Due to its mobility and smaller aspect ratio, the mask holder we recreated according to the design in the manual was flimsy, its joints tended to disconnect and it could not be reliably taken into and out of R1 without breaking apart. Towards improved structural integrity, we added a number of features:

- Used water pipe PVC which has smaller inner diameter (thicker walls)
- Used threaded T and L connectors for stronger joints
- Used Teflon tape on non-threaded joints for improved joint strength
- Reinforced the lower joints with aluminum rods to improve balance

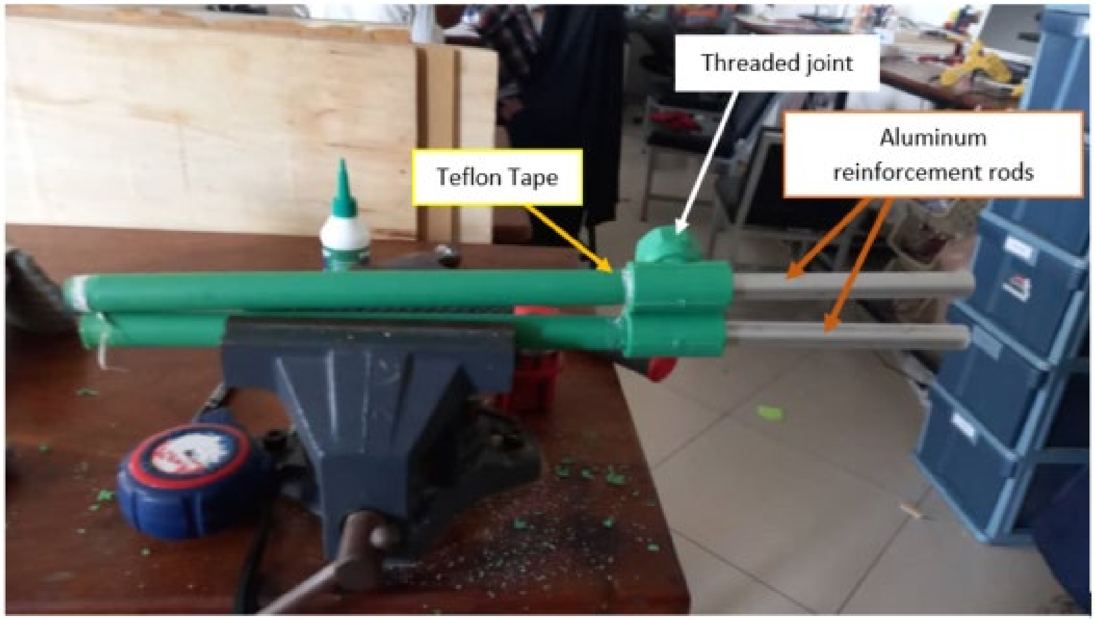


Figure 6 Bottom mask holder parts showing changes

VI. Wall placement of lights and foil

Due to the small size of the room, the lights were mounted and the foil was applied directly to the wall.

Testing and Validation

One of the primary objectives of the construction of the first room was to locally define best practices before system roll out to the 7 other rooms. Further, as the technology is new in Tanzania, we wanted to collect a significant amount of information to help substantiate our claims to the MNH Engineers. Thus, the Design Studio conducted experiments to validate the system. The full report on our testing and validation, including methods can be found here.

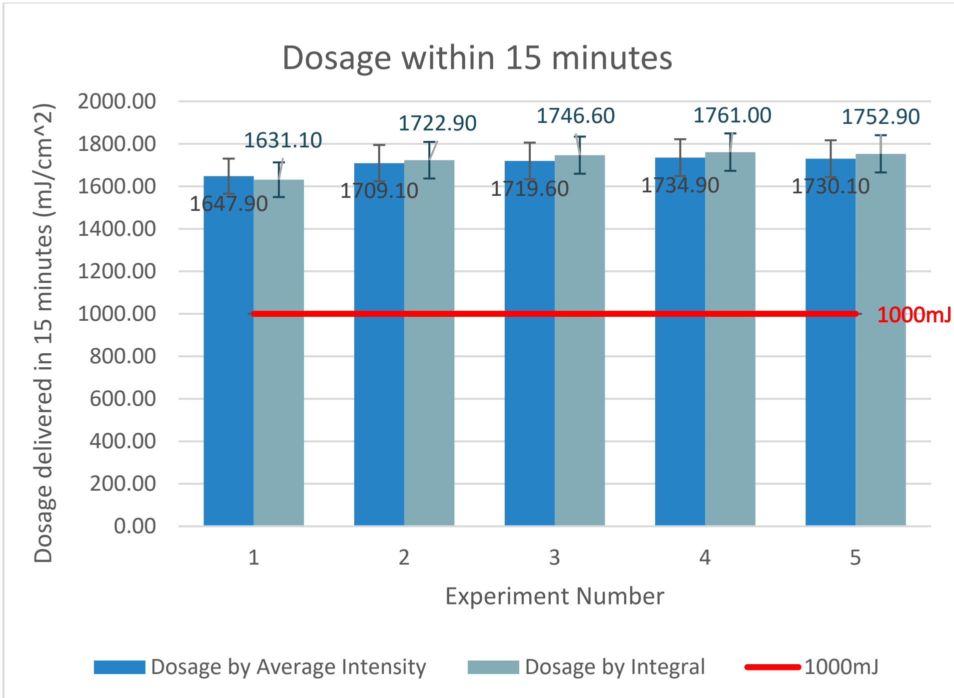
The graph below shows the dosage delivered in each of 5 rounds of irradiation as calculated via:

- Integral (i.e. area under the time/intensity graph calculated by the trapezoid method where dx = 60 seconds)
- Average (A simple calculation of the average reading over 30 minutes multiplied by fifteen minutes)

Our results show that:

• Calculating the dosage by integration (i.e. taking into consideration variation of intensity over time within first 10 minutes) and calculating dosage by average values led to comparable (<5% variation) values of dosage.

- The UVGI system delivers well over 1000mJ/cm^2 of UVC within 15 minutes of operation.



We also measured the average intensity at each mask location on the holder. The mask holder locations are named by matrix rules (i.e. position 2, 2 is on the 2nd row and 3rd column of the device when read from the top left).

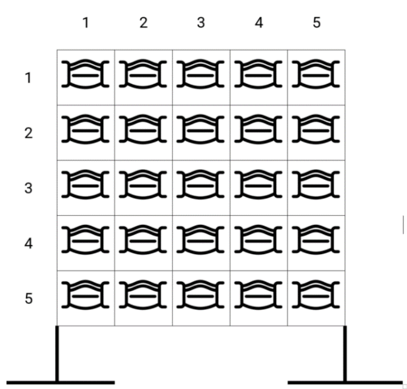


Figure 7 Mask position naming convention

Results from the experiment are detailed in the tables below.

FRONT

	1	2	3	4	5

1	1.84	2.17	1.9	1.7	1.27
2	2.53	2.45	2.28	2.16	1.32
3	2.58	2.36	2.1	2.09	1.53
4	2.91	2.48	2.11	2.23	2.17
5	2.03	2.14	2.09	1.97	1.52

BACK

	1	2	3	4	5
1	2.18	2.14	1.81	1.63	1.9
2	2.52	2.36	2.08	1.93	1.46
3	2.56	2.31	2.12	1.91	1.76
4	2.75	2.23	1.98	1.69	1.55
5	2.21	1.72	1.62	1.48	1.33

The results show that both sides of each mask location receive UV-C irradiation at an intensity that delivers well over 1000mJ/cm^2 of UV-C within 15 minutes.

NB: *Column 5 of the UVGI system was removed in the final iteration of the device. This was to improve mobility of the mask holder into and out of the room.*

The final version of the room disinfects 20 N95 masks in 15 minutes.

Training

We defined three distinct levels of interaction with the UVGI system, each that corresponds to its own bespoke training requirements. You can find all training manuals and presentations here.

1. **User**– anyone in the ward who wears an N95 face mask (patients, healthcare workers, patients' parents and guardians)

2. **Operator** – selected individuals who have passed through the Operator Training Course. The only people allowed to operate the room. (TLM cleaners)

3. **Technician** – selected individuals who have passed through the Technician's Training Course. The only people allowed to perform maintenance on and repair the UVGI system. (MNH biomedical engineers and technicians)

User Training

Users have no interaction with the UVGI system. They are required only to place, label and return their masks to and from specially labelled bag in a specially designated room. Although the DIT

Design Studio trained some users, most will be trained by the TLM staff. Save the labelling, the Pediatric Oncology ward had already incorporated a centralized mask collection system.

Operator Training

We authored an Operator Training Manual that detailed function of system parts, safety considerations and operating procedure of the UVGI system. Each operator was given a personal copy of the manual and had to undergo a practical where their skills in mask placement, room operation and mask retrieval were honed. You can find the complete operator manual here.

Figure 8 TLM cleaner places masks on the holder during user training

Technician's Reviews

We also authored a technician's training manual which detailed the system safety consideration, detailed operating principle, dosage calculation guidelines, troubleshooting steps and care and maintenance protocol. To read the technician's manual in its entirety, please click here.

Recommended Preventative Maintenance Schedule

After each use	❏ Record time used in log book. ❏ Disinfect UVGI room door knob, switch and mask carrying cart. ❏ Document preventative maintenance actions taken.
Weekly	❏ Conduct picture test (*SEE INSTRUCTIONS BELOW*) ❏ Check foil covering for tears and peeling, patch with new foil and glue/tape as needed. ❏ Test UV output using lightmeter (one location on frame)

	❑ Document preventative maintenance actions taken.
Monthly	❑ Perform **Weekly** preventative steps. ❑ Test UV output using lightmeter (at least 5 locations on frame) ❑ Check hooks and repair/replace as needed. ❑ Check system wiring and connections. ❑ Verify mains power voltage output. ❑ Document preventative maintenance actions taken.
Quarterly	❑ Perform **Monthly** preventative maintenance steps. ❑ Conduct dosage check test (*SEE INSTRUCTIONS BELOW*) ❑ Test UV output on each location of the PVC frame. ❑ Document preventative maintenance actions taken.
Annually	❑ Conduct **Quarterly** maintenance. ❑ Document preventative maintenance actions taken.

TROUBLESHOOTING

Failure	**Probable Cause**	**Components to Check**
UV lamps do not turn on	Main switch off/disconnected	Check connections on inner main switch and extension cord.
	Loose wiring/connectors	Check connections as above and connections to lamp connectors and ballasts.
	Broken ballasts	Replace ballast.
Torn Aluminum foil	Scraping	Repair with aluminum foil sheets/ aluminum foil tape. Ensure shiny side is facing the room.
Failed picture test	UV lamp disconnected from connectors	Check connection between UV lamp ends and connectors.
	Defunct UV lamp	Replace lamp.
	Defunct ballast	Replace ballast.
Failed intensity test	UV lamp connections are disconnected	Check lamp, ballast and extension cord connections.

	Power to the system is not at standard level	Check the wall power using a multimeter to confirm 220-240V supply.
	Aging lamp tube	Conduct dosage check.

We have not been able to run a technician's training session. Engineers have attended our operator training and conversations with MNH Engineering are ongoing.

Figure 9 DS Coordinator training users and technicians on the UVGI system

During our reviews with the MNH engineers, they identified features that should be added to an ideal system:

- Micro switch wired to automatically shut off the system in the event that the door is opened during operation
- Automatic timer with an alarm/indicator that alerts a user when the dosage is sufficient.
- A system to detect light defects during every single round of operation.

User evaluation

The DIT Design Studio has finalized all the technical portions of R1 and we are currently waiting for evaluation information from TLM.

Invention Education

With all projects taken on by the DIT Design Studio, our goal is to accord our members opportunities for invention education.

During last year's Industrial Practical Training, three of our diploma IPT level students were tasked with creating the mask holder of the device. Students had to adapt the manual instructions according to the constraints of the room we were provided. They also had to procure all parts and assembly a sturdy mask holder that could be reliably moved into and out of R1.

Figure 10 IPT students building the first mask holder

In addition to IPT, our members (graduate and students) provided labor for key parts of the construction and testing and validation steps of the project. One diploma level Laboratory Tech student helped us put up the aluminum foil on the system walls. Another member, a graduate diploma in Mechanical Engineering student worked on collecting data for the experiments presented in the Testing and Validation document.

Finally the project offered our new technicians (both of whom are former DIT students and studio members) opportunities to engage in higher level design tasks. Both technicians managed the student contributions to the project, suggested material/fabrication step changes and contributed to the writing of the experiment methods. Following Rice 360°'s commitment to grow the studios sustainably by allowing skills transfer to local talent, the project allowed the technicians to deal with a more complex problem as they prepare to take over an increasing number and complexity of Design Studio tasks.

Figure 11 Members, technicians and the electrician during construction

Finances

Original Proposed Budget (R1 only)

For a detailed breakdown, please see here.

Item	Budgeted cost (USD)	Budgeted cost (TZS)	Notes
UV supplies	-	-	Shipped from the US - Germicidal lamps, ballasts, UVC lightmeter, 901hor socket
Local Materials	$276.54	TSh641,300	Electronic wiring, foil, glue, wood, PVC and piping
Labor	$53.90	TSh125,000	Cleaner, electrician & volunteer proceeds
Bulk costs	$43.12	TSh100,000	Transportation, incidentals
TOTAL	**$373.57**	**TSh866,300**	

Actual Expenditure

For a detailed breakdown, please see here.

Item	Actual cost (USD)	Actual cost (TZS)
Local Materials	$272.52	TZS 626,800.00
Labor (Electrician)	$65.22	TZS 150,000.00
Transport	$35.91	TZS 82,600.00
TOTAL	**$373.65**	**TZS 859,400.00**

Additional Expenditure

To present the best case to the MNH engineers, we decided to conduct more extensive testing and validation than planned in the first budget. Thankfully we were able to draw from our funds from the Irish Embassy via TLM. These funds are yet to be disbursed and actual amounts will be shared as soon as disbursement is completed.

Requirements	Total cost (USD)	Total Cost (TShs)	Notes
Labor		TSh105,000	7 days of work
Dosimeter cards	$300.00		
Dosimeter cards shipping	$50.00		
Project admin		TSh200,000	(transport, airtime vouchers, PPE)
TOTAL	**$350.00**	TSh305,000	

Next Steps

MNH Engineering has requested that we apply for certification from the Tanzania Medical Devices Association before we can proceed with more rooms. There is also the opportunity to take the project to other hospitals with a greater dearth of resources.

Thanks

We want to offer special thanks to Mr. Jackson Coole, a graduate student in Rice University's Bioengineering Department and the principal author of the UVGI manual. Jackson provided advice during every stage of our evaluation, construction, procurement, validation and training processes. His input was invaluable and we greatly appreciate all the work he put into helping us achieve this. Thank you, Jackson!

The DIT Design Studio would also like to thank the following organizations

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- Rice 360° Institute of Global Health
- Rice University Department of Bioengineering
- Muhimbili Pediatric Oncology Ward
- Dar es Salaam Institute of Technology
- Irish Embassy Tanzania

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- Project electrician Ally Major
- Data collector Joshua Kitigwa
- All the DIT Design Studio members who participated in the construction of R1