Spacecraft Lighting to Mitigate Microbial Growth

JOHNSON SPACE CENTER INNOVATION CHARGE ACCOUNT PROJECT SUMMARY

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Investigating Novel Ways to Curb Microbial Growth on Spacecraft

- In this innovation project, we investigated the usage of narrow band violet light (408 nm) to attenuate the growth of bacteria typically found on ISS.
- Violet light is less hazardous than UV light and it can transmit through plastics, such as clear acrylics, making it possible to incorporate into large surface lamps and acrylic or polycarbonate based optical light guides.
- This study built a custom LED surface panel that was edge lit by an array of 408 nm violet LEDS. The optical light guide technology used in the lamp and the 408 nm violet LEDs are available on the market from multiple vendors.
- The application of the concept of using violet light driven LED panels and optical light guides is to integrate the paneling into spacecraft architectural surfaces for the automation of a light based microbial countermeasure that could enhance current cleaning methods used in areas on spacecraft prone to microbial growth.

Why Direct Surface Irradiation?

- Microbes such as bacteria tend to grow on surfaces, especially where there is moisture present.
- A typical small "lamp" housing, where the LED array is directly facing the aperture of the lamp, can emit light over a volume, with that light eventually striking a surface. Any objects in the way of the planned surface will block light to that surface. The inverse square law of light also causes a diminishing return on intensity the farther the intended surface is away from the lamp.
- New LED optical light guide technologies, allow for the realization of unique lamp configurations where the lamp can be the architectural surface to be treated while also providing beneficial light to irradiate objects within a volume.

Evaluation Process

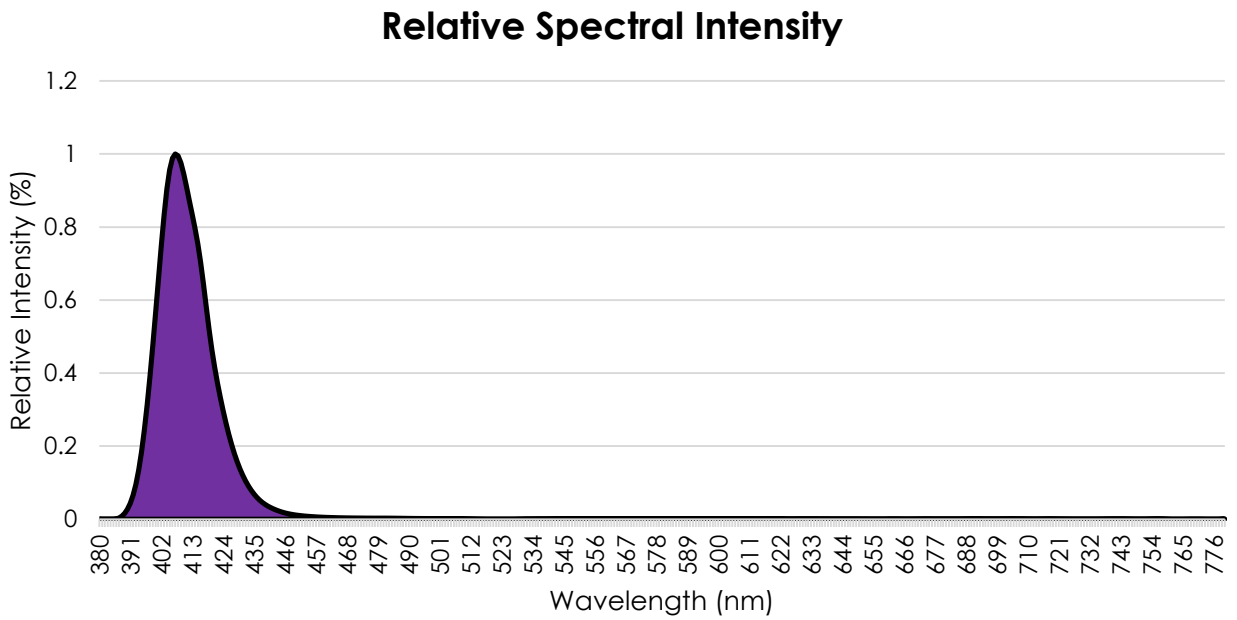
- Four 1x1 foot violet LED panels were manufactured. Each panel is less than a quarter of an inch thick.
- Each lamp was installed in flat, black interior, "pizza box", that had lid who's interior surface was lined with black velvet. The box was necessary to ensure testing of specimens was limited to the violet light source.
- The lamps were connected to a precision pulse-width-modulation (PWM) LED dimmer driver to precisely control percent intensity output.
- At JSC's microbiology lab, bacteria cultures (*Enterobacter aerogenes & Staphylococcus aureus),* in clear Petri dishes, were placed directly onto the lamp surface, enclosed in the box, and irradiated for different amounts of time and intensity.
- Growth was compared against a "Control" (no light) vs. "Light" (violet light ON)
- Bacteria was counted before and after irradiation to determine impacts.

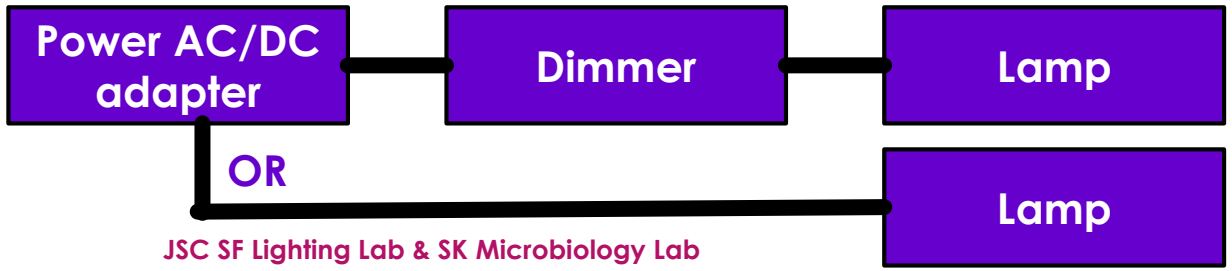
Bacteria Test Method Details

- Bacteria were streaked out onto TSA plates and maintained in culture.
- An isolated colony was then inoculated into 3 mLs of TSB and cultured at 35°C while shaking to either logarithmic phase or stationary phase.
- Cultures were then serially diluted and 100 µL was spread onto plates in duplicate.
- Plates were then irradiated by violet light panels for either 1, 2, or 3 hours.
- The control plates and irradiated plates were then incubated at 35°C over night.
- Plates were then enumerated using a plate count method.

Lamp Configuration & Irradiance Data

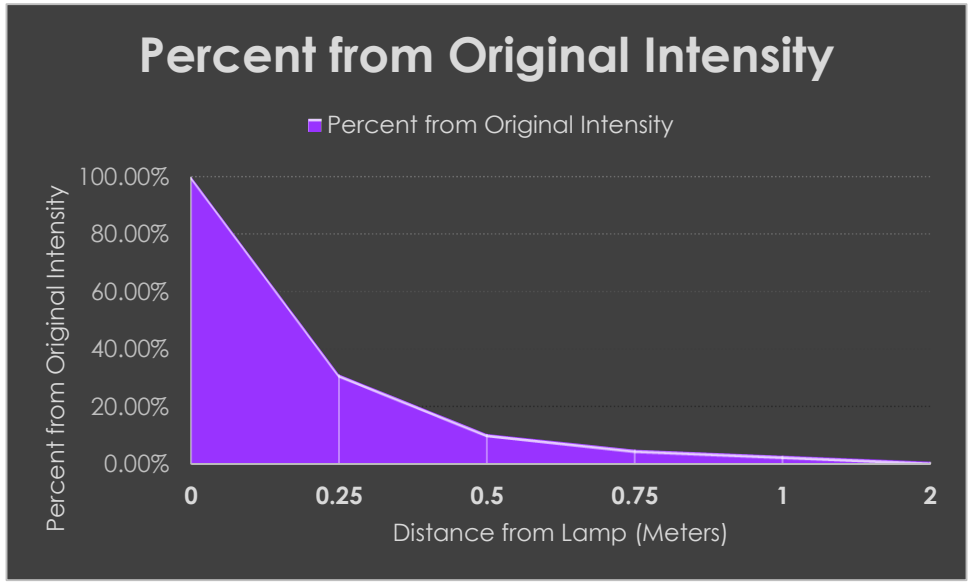
Dimmer Setting (% ON)	LOG Dimmer Setting Irradiance (watts/m^2) @ 407nm	LINEAR Dimmer Setting Irradiance (watts/m^2) @ 407nm
100	0.616650105	0.618251979
90	0.513876259	0.553633928
80	0.41501689	0.496556014
70	0.325845122	0.433516979
60	0.248668224	0.370118678
50	0.179880083	0.306409627
40	0.122767307	0.245538756
30	0.074601203	0.182887971
20	0.037911151	0.122212842
10	0.012393613	0.060458016





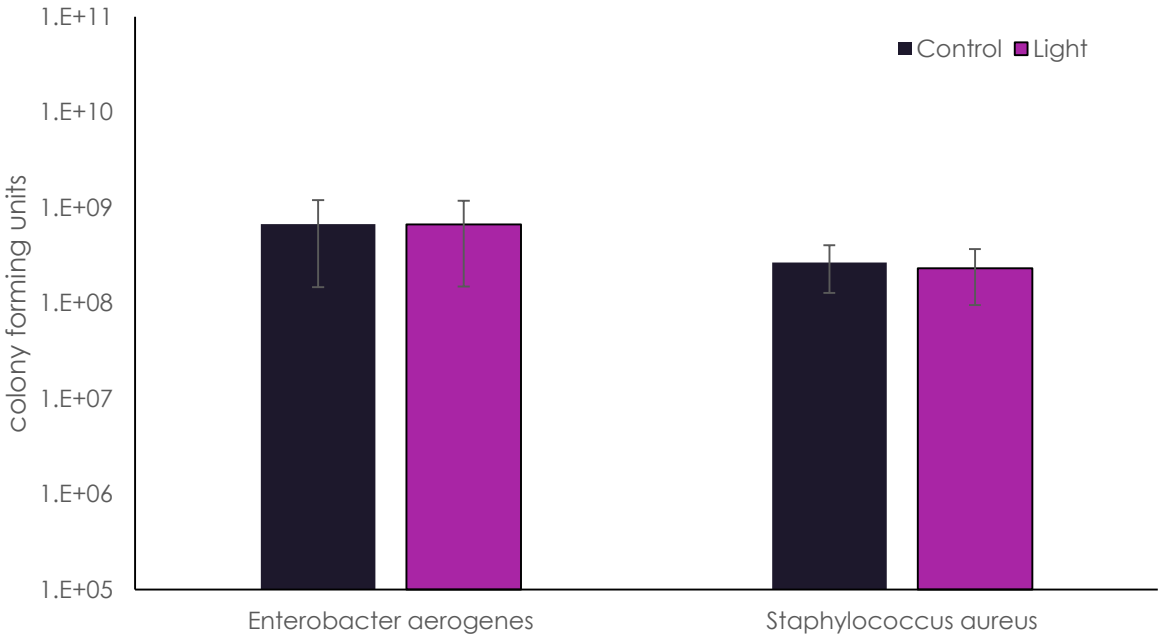
Application Design Concerns

- There is no guarantee that surface lamps, such as the ones tested, will represent the energy output of lamps NASA might fly in the future. Spacecraft have lots of rules on weight, power, and heat emission that could limit the intensity and size of lamps we could integrate into an architecture.
- Consideration needs to be made that there will be some applications where both the lamp surface is the treatment area and surfaces beyond the lamp need treatment. ISS corridors provide approximately two meters of clearance. The chart "Percent from Original Intensity" shows predictions on loss of intensity verses distance.
- If sanitation procedures are done during sleep time or non-use time periods, the potential exposure or "on-time" of a violet light protocol, could be 6 or more hours. Consider time not in waste-hygiene-compartment, not in crew quarters, not exercising.

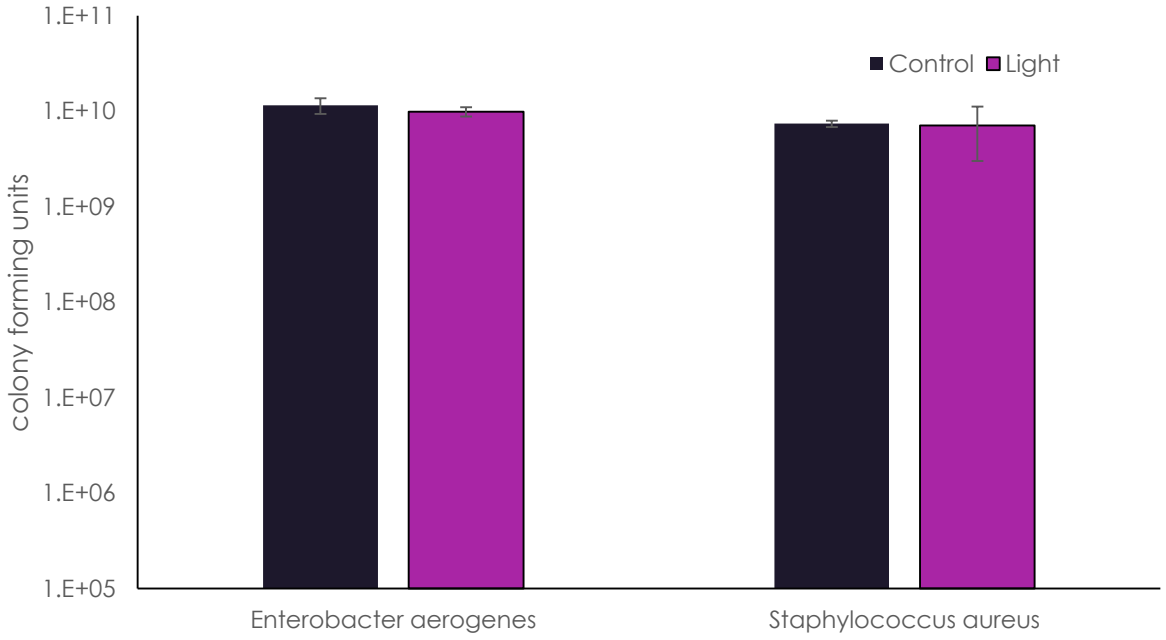


Results from 1 Hour of Testing @ 100 %

A.



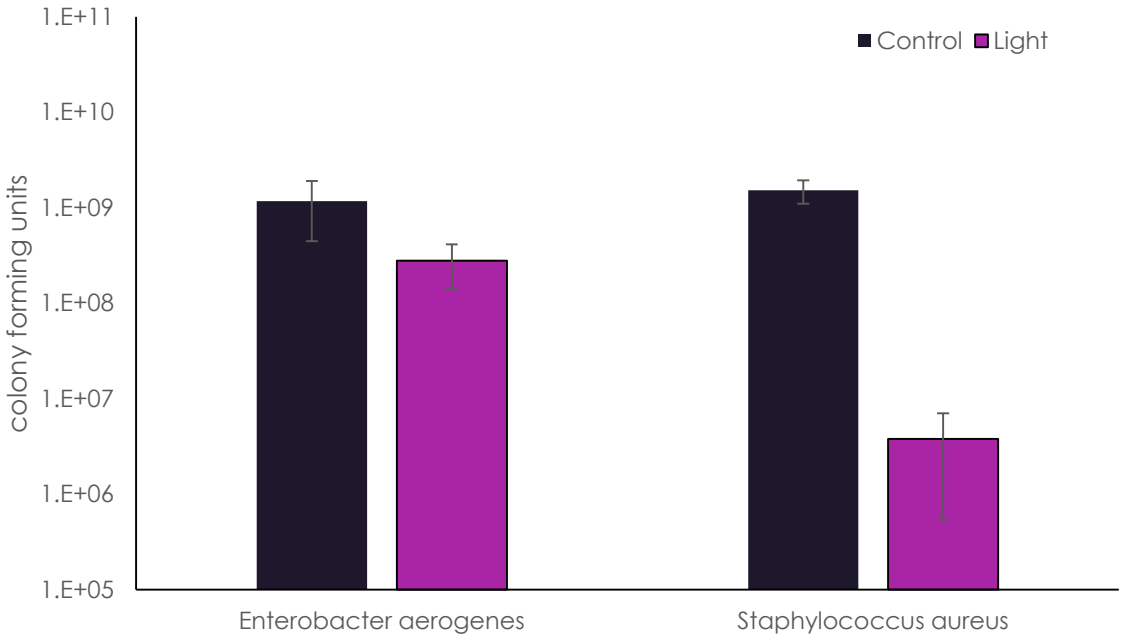
B.



The germicidal activity of a one hour exposure to violet light was tested using two bacterial isolates from the International Space Station. Bacterial cells were cultured in liquid media prior to being irradiated. (A) Cells cultured to the logarithmic phase of growth (4 hours) (B) Cells cultured to stationary phase of growth (24 hours). Experiments were performed in biological duplicate.

Results from 2 Hours of Testing @ 100%

A.



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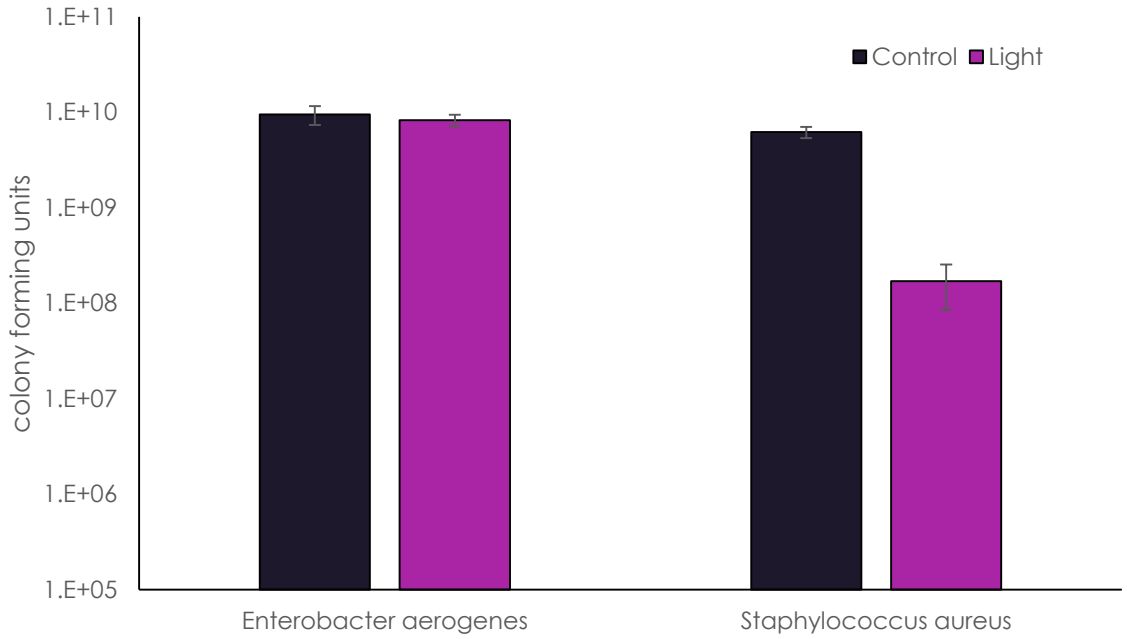
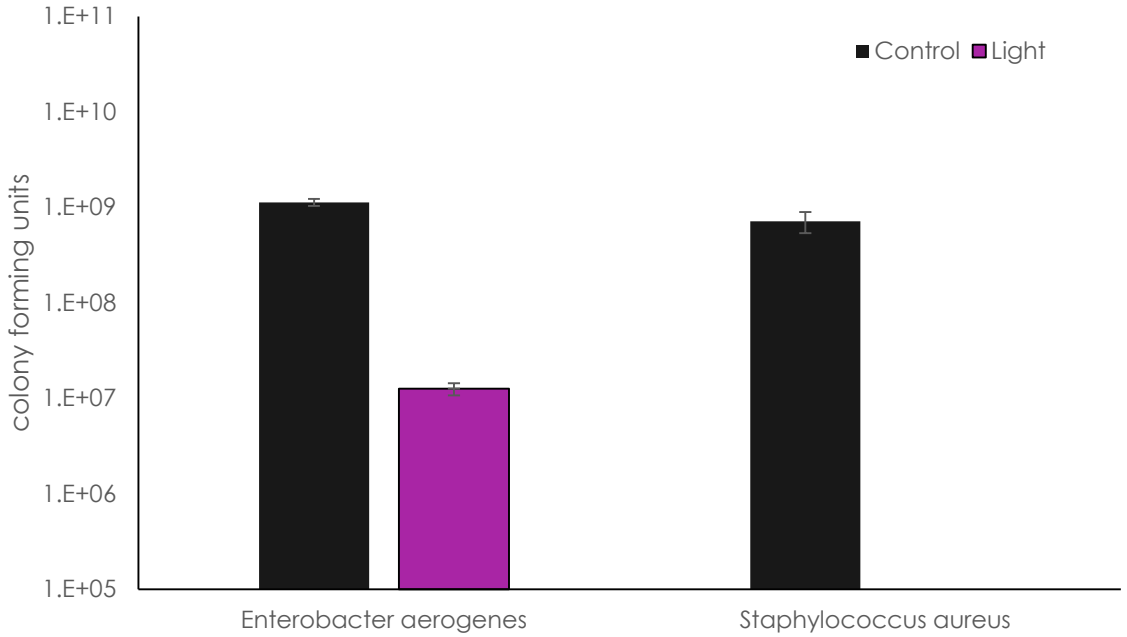


The germicidal activity of a two hour exposure to violet light was tested using two bacterial isolates from the International Space Station. Bacterial cells were cultured in liquid media prior to being irradiated. (A) Cells cultured to the logarithmic phase of growth (4 hours) (B) Cells cultured to stationary phase of growth (24 hours). Experiments were performed in biological duplicate.

Results from 3 Hours of Testing @ 100%

A.



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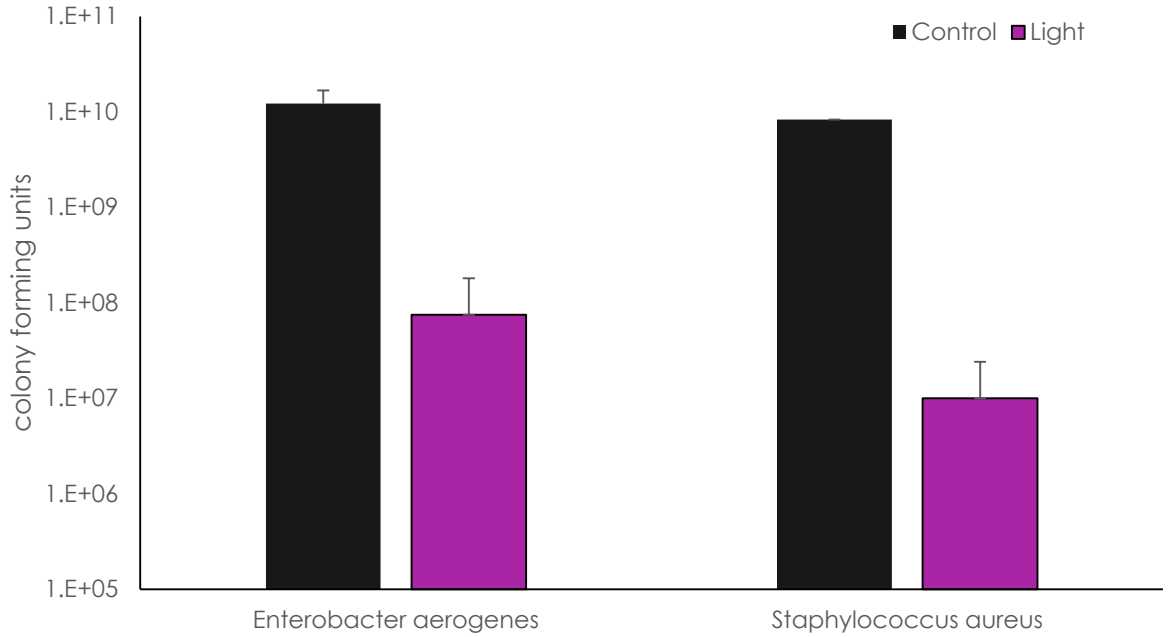
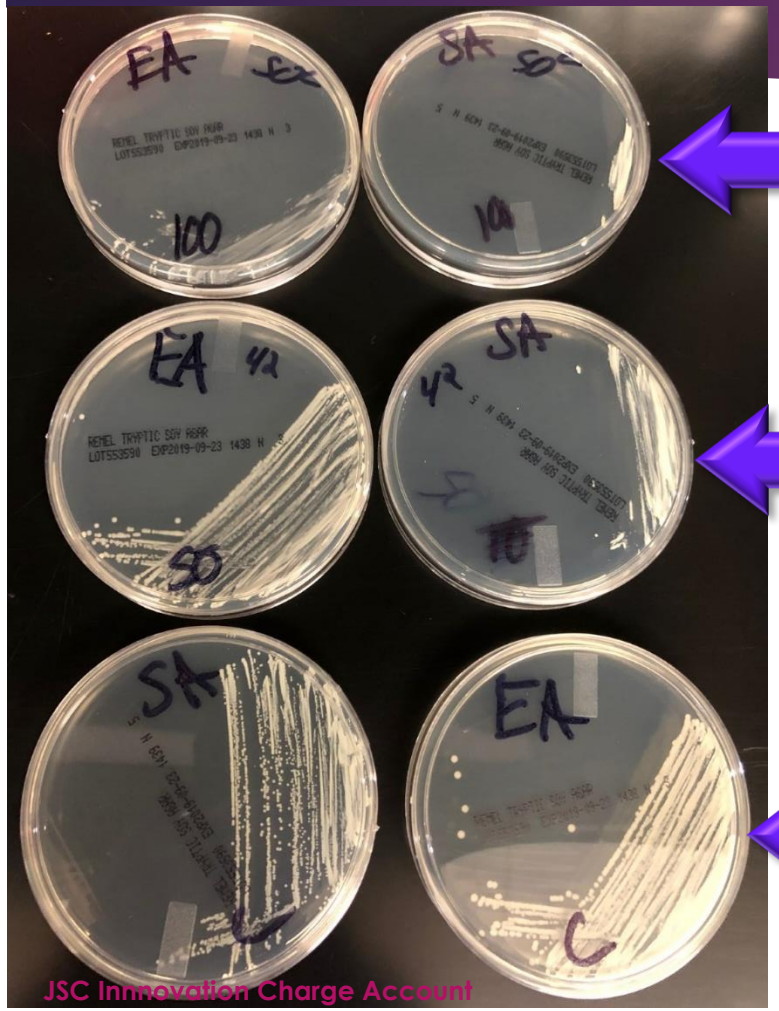


The germicidal activity of a three hour exposure to violet light was tested using two bacterial isolates from the International Space Station. Bacterial cells were cultured in liquid media prior to being irradiated. (A) Cells cultured to the logarithmic phase of growth (4 hours) (B) Cells cultured to stationary phase of growth (24 hours). Experiments were performed in biological duplicate.

Typical Growth Plates Used in Testing



100% power for 15 Hours:
Temperature inside was ~50°C
Enterobacter aerogenes (left)
Staphylococcus aureus (right)

50% power for 15 Hours:
Temperature inside was ~42°C
Enterobacter aerogenes (left)
Staphylococcus aureus (right)

Control:
Temperature was ~35°C
Enterobacter aerogenes (right)
Staphylococcus aureus (left)

Image shows example of typical bacterial growth plates. The intensity of the lamp has a direct impact on the health of the colony.

Usage of the countermeasure needs to consider dosage and exposure time.

Discussion & Results

- *Enterobacter aerogenes* is less susceptible to violet light when compared to *Staphylococcus aureus. Staphylococcus aureus* is sensitive to violet light disinfection.
- Bacteria growth is still impacted but appear to be more resistant to violet light when in stationary growth phase as compared to logarithmic phase.
- Initial testing shows much potential for the technology.
- Successful application of this potential technology requires planning on targeted zones for a microbial countermeasure, determination on required irradiance levels, and development of practical exposure times that accommodate both crew activities and effective light-dosage.

Forward Work

- The initial findings from testing and analysis performed for this Innovation Charge Account project has shown that usage of violet light to curb the bacteria tested does make an impact.
- Future larger studies need to be performed on more complicated light emitting surfaces and optical light guide implementations.
- Future testing at different exposure levels and a larger range of microbes (other bacteria, fungus, and virus species) should be run to determine the extent of the usability of the countermeasure.
- Conceptual architectural and end-item lamp design concepts and analysis needs to performed to determine effective implementation and design requirements.