Summary of Findings from Testing of Phosphorescent Finalists for IRC 2024 Open-Innovation Challenge Titled "Application of Phosphorescence Technology for Toilet Lighting in Refugee Camps"

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Contents

The Tested Units

Between 12 December 2024 and 29 January 2025, three different designs for phosphorescent lighting of female latrines were tested in New Providence, NJ. The three designs were:

- ID 129087 – "Phluo" rectangular panel by Marco Miglioli. See Figure 1.
- ID 129172 – "Honeycomb" rectangular panel by Molly Simmons. See Figure 2.
- ID 129190 – "Night Skylight" light tunnel-based units by Russel Donovan. See Figure 3a&b.

Figure 1. Top and Bottom of Phluo.

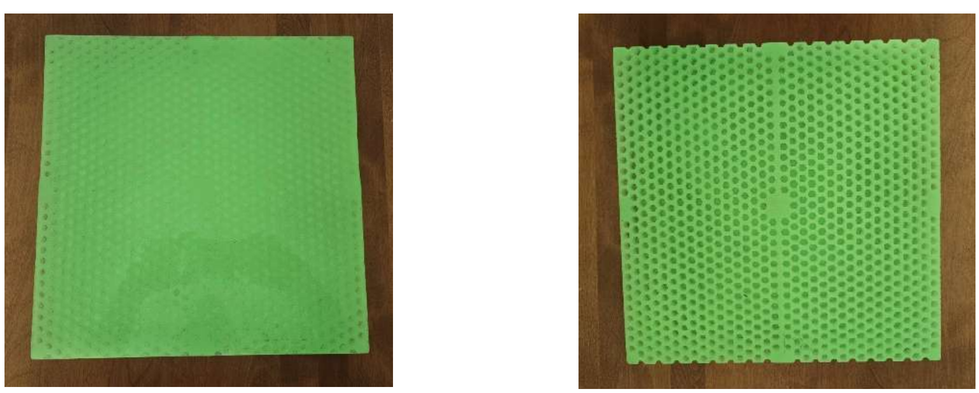

Figure 2. Top and Bottom of Honeycomb.

Figure 3a. Top and Bottom of Large Night Skylight.

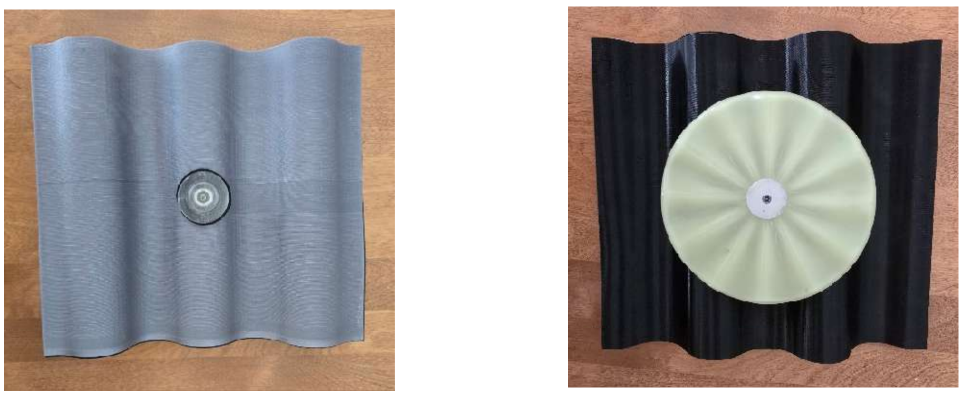

Figure 3b. Top and Bottom of Small Night Skylight.

The three finalists each had a different design emphasis, as follows:

- The Phluo is designed so that it can be manufactured locally in a refugee camp. The prototype unit is 25cm x 25cm x 0.5cm. However, the units can be made in any shape and can likely be made to conform with the shape of a corrugated roof panel. This flexibility is a key aspect of the design. The prototype used 70g of phosphorescent material.
- The Honeycomb is designed to create greater surface area for light emission through a honeycomb pattern on the inside side of the unit. The prototype unit is 36cm x 36cm x 1.4cm. The solver claims this provides greater strength to the panel and more light from one side of the panel. The prototype used 400g of phosphorescent material.
- The Night Skylight is designed to install in the roof of a latrine with only a 2cm (diameter) hole in the roof. It claims to get light to a round phosphorescent disk through a 'light tunnel' which can charge the unit without direct sunlight. There are two prototype units: one with a disk of diameter of 220mm and one with a disk of diameter of 135mm.   The large prototype used xxg of phosphorescent material. The small prototype used xxg of phosphorescent material.

The Testing Process and Summary Results

The general pattern for testing was to leave the units outside in an area with little or no shade and a southern and western exposure for different amounts of time ("charge"). See Figure 4 for a typical location for charging. At dark, the units were brought to a dark basement and they were periodically tested for light output (“discharge”). When the units were not being tested for light output, they were stored in separate covered boxes. See Figure 5.

Figure 4. Typical charging location.

Figure 5. Storage of phosphorescent units when not measuring light output. From left to right: Honeycomb, Phluo, Large Night Skylight, Small Night Skylight.

Outside temperatures were below 0 ºC. Basement temperatures were about 20 ºC. Charging times ranged from 4 to 10 hours. Discharge measurements were done up to 14 hours after charging ended.   All told, the charging/discharging cycle was documented on fourteen different days.

Light output was measured with a portable light meter by Dr. Meter. The model # was LX1330B. This light meter could measure light with sensitivity of 0.1 Lux. See Figure 6a. The light sensor was held about 1.4 cm above the light source when recording light output. See Figure 6b.

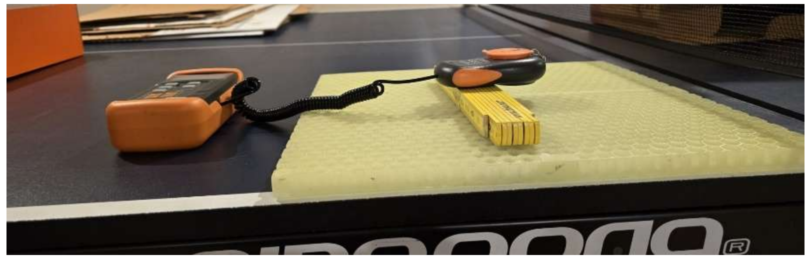

Figure 6a. LX1330B. **Figure 6b. Light measurement setup**

The four prototypes are shown in Figure 7 immediately after 10 hours of charging in direct sunlight. After the photo was taken, the units were each placed in a separate covered box. The same units were then photographed in the same location four hours later in Figure 8. In both cases, the pictures were taken in a dark room with a cellphone camera on a Samsung Galaxy S24 Ultra. They were not enhanced or edited in any way.

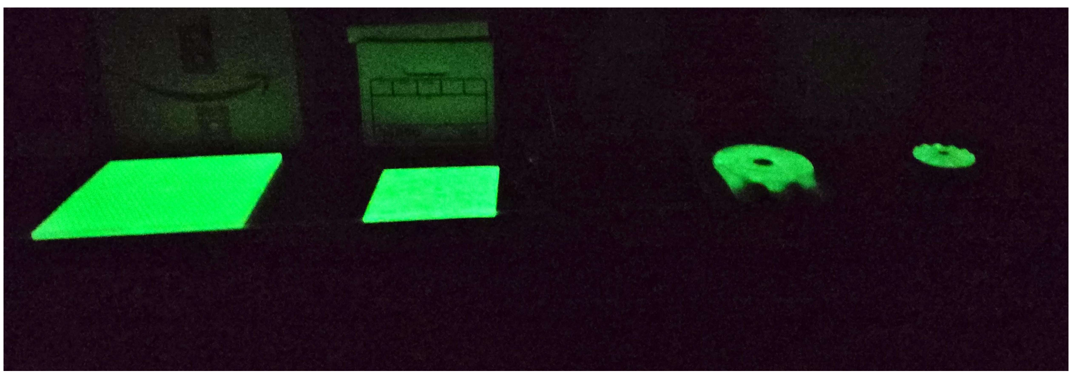

Figure 7.
(left to right) Honeycomb, Phluo, 220mm Night Skylight, 135mm Night Skylight on 29-Jan-25 at 5:20 pm (immediately after sunset).

Figure 8.
(left to right) Honeycomb, Phluo, 220mm Night Skylight, 135mm Night Skylight on 29-Jan-25 at 9:15 pm (4 hours after sunset).

The camera does not adequately capture the light profile of the test units. One's ability to see with the phosphorescent light depends on the brightness of the unit, the adjustment to darkness for one's eyes and the color of the objects around the area where the light is falling. To try to eliminate subjectivity from the process, light measurements from the Lux Meter are summarized in the table below. Full information from the test results is available in Appendix 1. The 'Set' referenced in the table below is the ID row from the data in Appendix 1. Detailed notes and photos from testing are in separate PDF documents with one document per testing date.

Time After Sunset (in H:MM)	Phluo Output (in Lux)	Honey-comb Output (in Lux)	Data recorded on
0:07	3.2	4	Set 15: 29-Jan-2025 at 5:07 pm
0:15	3.3	3.5	Set 12: 26-Jan-2025 at 5:15 pm
0:17	2.7	2.8	Set 6: 16-Jan-2025 at 5:17 pm
0:40	1.5	1.85	Set 15: 29-Jan-2025 at 5:45pm (see field notes)
3:10	0.15	0.25	Set 12: 26-Jan-2025 at 8:20 pm
3:37	0.1	0.2	Set 6: 16-Jan-2025 at 8:35 pm
4:02	0.1	0.1	Set 15: 29-Jan-2025 at 9:15 pm
4:40	0.05	0.15	Set 12: 26-Jan-2025 at 9:50 pm
11:30	0.01	0.01	Set 12: 26-Jan-2025 at 6:40am of next day
12:07	0.01	0.01	Set 15: 29-Jan-2025 at 7:20am of next day
12:32	0.01	0.01	Set 6: 16-Jan-2025 at 5:32am of next day

Table 1. Test Results.

See Figure 9 for a plot of the light output versus discharge time. The trendlines that Excel creates are not perfect fits for the data but they provide a good approximation of the rapid decay of luminosity of the two most powerful test units.

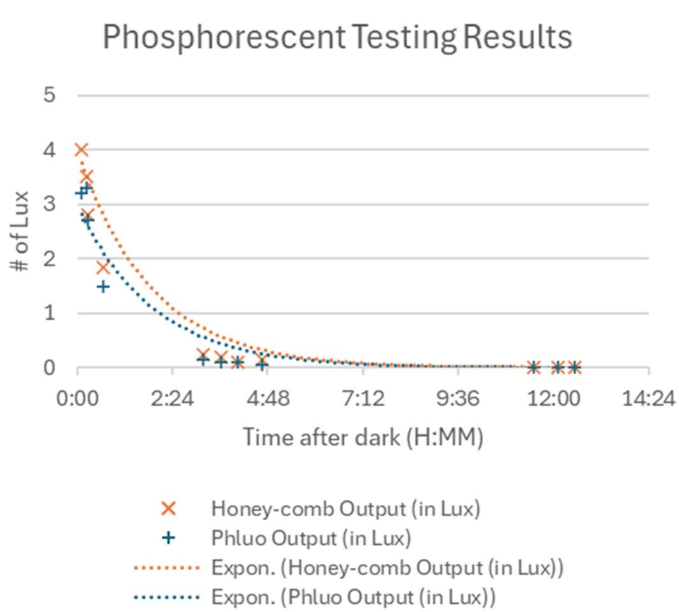

Figure 9. Phosphorescent Testing Results.

Discussion of Findings

This extended testing process revealed many valuable insights into the performance of phosphorescent materials in general and a few unit-specific insights as well. This section discusses each category separately.

General Observations

1. **Behavior of Phosphorescent Materials**
    a. **Rapid reduction in light intensity.** There was a steep decay in the light output for all of test units during the first few discharge hours. However, then the decay rate slowed substantially and almost seemed to stop decaying after 6 or so hours. Then, a long period of a small but meaningful amount of light lasted more than 12 hours.
    b. **Temperature changes affect the light intensity.** This was not extensively tested, but changes in temperature sometimes had a meaningful effect on luminosity. For example, on 23 January (Test Set 9), the Large Night Skylight had a reading of 0.2 Lux at 5:00pm when it was brought inside from -4 ºC to 20 ºC. At 5:07pm, it produced a reading of 0.3 Lux. At 5:11pm, it produced a reading of 0.4 Lux.
2. **Charge/Discharge characteristics**
    a. **A minimum number of hours of charging is necessary – probably at least 6 hours.** A number of the test sets were focused on determining a relationship between the number of charging hours and obtaining the optimal discharge behaviors of longevity and brightness. We concluded that the units can perform at full potential with a full day of daylight (at least 10 hours). If, for some reason, a unit could not be in light for a full day, it would still obtain a significant amount of charging, but it would not perform as well as with a full day of charging. See column 'E' in Appendix 1.
    b. **Ambient light can do a meaningful amount of charging.** Test sets 8, 9, 10, 11, 13 and 14 discovered and then focused on learning about the impact of ambient light on the charging of the phosphorescent units. When comparing the results of Test sets 14 and 15, our conclusion is that the initial luminosity of the units was less with no direct sunlight, but ambient light can generate close to the same longevity as direct sunlight. This was a major surprise.
    c. **The emission of light can last long after the last exposure to sunlight.** The panel units (Honeycomb and Phluo) demonstrated that the total decay to zero light takes a very long time for strontium-aluminate-based units. On 1 February 2025, about 60 hours after the last measurement from Test Set 15, the two panel units were removed from their covered storage boxes and they still had enough light output that one could see the interior of the box clearly. The light output was not measurable with the Lux Meter but there was a potentially useful output of light.

3. **Physical characteristics of test units**
    a. **The number of sq-cm of surface area of a test unit directly affects the useful light available from a test unit.** Table 2 shows that the four test units were significantly different in their shapes and this led to a significant difference in the amount of useful light that each produced. The useful light from a test unit was directly related to both its luminosity (# of Lux produced) AND it surface area. For a

given amount of luminosity, the bigger the form-factor of the physical unit, the more useful light will be available.

Unit Name	Configuration	Surface Area (sq-cm)
Honeycomb	36x36 cm square	1296
Phluo	25x25 cm square	625
Large Night Skylight	22cm diameter disk	380
Small Night Skylight	13.5cm diameter disk	143

Table 2. Surface Area of Test Units.

b. **The amount of phosphorescent material in a test unit directly affects the luminosity of the unit.** The Honeycomb unit was 0.8 cm thick, the Phluo unit was 0.5 cm thick, and each Night Skylight was a 3-D printed to be perhaps 0.1 cm thick. The intensity and longevity of the light output from the Night Skylights was substantially inferior to the other two test unit. We believe this is largely due to the much thinner thickness of these two units and the subsequent significant reduction in phosphorescent material to absorb light. There was not a material difference in performance between the Honeycomb and the Phluo units.

c. **The phosphorescent material used did not seem to make much difference in the performance of the units.** All three solvers used different suppliers for their strontium aluminate but we could not see a material difference in performance. This suggests that the chemical composition of products from different vendors is similar and that price and other factors might be more important in selecting a vendor to work with.

Unit-Specific Observations

4. **Honeycomb**
   a. **The honeycomb side of the test unit was slightly brighter than the flat side of the test unit in the first couple of hours but not after that.** The solver's submission placed great emphasis on the value of the honeycomb pattern for generating more usable light. Our testing methodology did not duplicate these results. If there was more light on the honeycomb side than the flat side, it only happened during the first couple of hours of discharge. At the 4-hour measurement time, there was no discernible difference between light output of the two sides.
   b. **Thickness of honeycomb panel likely not necessary.** The honeycomb panel was 0.8 cm thick. While this made the panel physically robust, the light output from the Phluo and the Night Skylight suggest that this thickness is not necessary to obtain valuable light performance.

5. **Phluo**
   a. **The panel thickness with phosphorescent material mixed throughout might provide a small 'honeycomb' benefit.** The Phluo is a flat square panel with phosphorescent material mixed evenly throughout the entire panel. The 0.5 cm depth of the panel seemed to duplicate the same positive light output as the Honeycomb but produce a lot more light than the Night Skylight. Our hypothesis is that the depth produced a pseudo-honeycomb effect that is valuable.

6. **Night Skylight**
   a. **The "Light Tunnel" is potentially valuable but the prototype did not validate its utility.** A number of test cycles were invested into understanding the amount of charging that happened through the 'Light Tunnel' of the Night Skylights (Test Sets 8, 9, 10, and 11). Our conclusion is that the Light Tunnel was only able to charge an area perhaps at most 1 cm wide immediately contiguous to the Light Tunnel. In Figure 10, there is a glow around the center of the Light Tunnel but it does not extend very far into the whole disk.

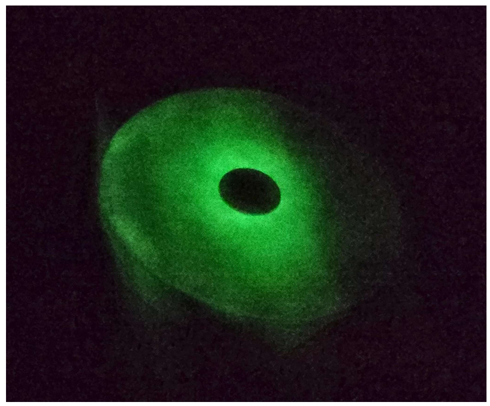

Figure 10. Large Night Skylight at 6:16 pm on 26-Jan-2025 after 8 hours of charging and 1:09 after sunset.

   b. **Most of the charging that happened with both Night Skylights happened from ambient light getting to the disks.** Both Night Skylights were tested by laying them flat on the ground with their corrugated-roof sections facing up. This allowed ambient light to get to the disks by bouncing off the ground and under the corrugated roof. Figure 11 shows the amount of glow that the Large Night Skylight got from this situation. It is brighter than the disk in Figure 10 and light is emanating from the entire disk.

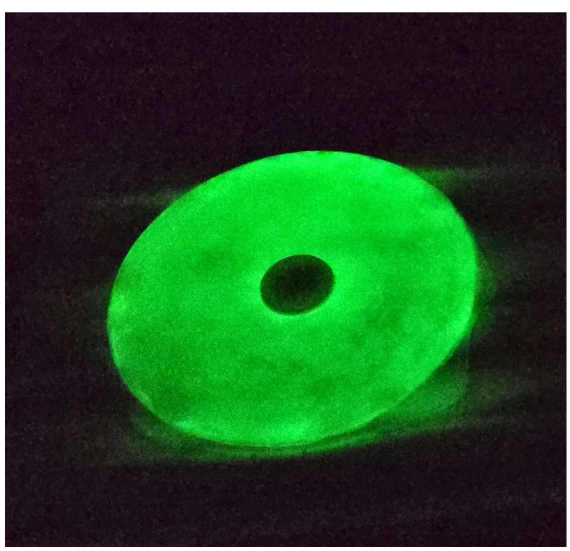

Figure 11. Large Night Skylight at 5:15 pm on 16-Jan-2025 after 7 hours of charging and 0:17 after sunset.

Appendix 1 provides Lux readings for each tested unit immediately after sunset, at ~4 hours after sunset and at ~12 hours after sunset. This organizes all the data collected during the various testing processes done during the month. To see pictures taken on each day and to read field notes from the testing, see the PDF of Field Notes. It is 57 printed pages.

Appendix 1. Detailed Data Collected (2 pages: side-by-side)

	A	B	C	E	F	G	H	I	J	K	L	M	N	O	P
1											Initial Reading Immediately After Charging Stops (Lux; with sensor 1.6cm above light source)				
2	ID	Testing Phase	Date	# Hours From Charging Start to Measurement Time	Time of Measurement	Time of Sunset	Direct-Sun Conditions in Placement of Units	Temp (F) (Start/End)	Test Objectives	Additional Light Measurements Taken?	Honeycomb	Phluo	Large Night Skylight	Small Night Skylight	Modified Small Night Skylight with Phluo on back
3	15	Finals	1/29/2025	10	5:20pm	17:13	All Sun	30/40	Measure long charge time in direct sun situation	Yes: 5:45pm	4	3.2	0.5	0.5	NA
4	14	Finals	1/28/2025	10	5:15pm	17:12	All Shade	37/35	Measure charging effect of only ambient light for 10 hours	No	2.6	3.1	NA	NA	NA
5	13	Finals	1/27/2025	5	5:30pm	17:11	All Shade	35/NA	Measure charging effect of only ambient light	No	1.6	1.6	NA	NA	NA
6	12	Finals	1/26/2025	6	5:25pm	17:10	All Sun	34/40	Verify baseline results	Yes: 9:50pm and 8:00am	3.5	3.3	0.4	0.5	NA
7	11	Finals	1/25/2025	9	5:30pm	17:08	All Sun	NA	Try to eliminate ALL light for large Night Skylight (enclose in box)	No	NA	NA	0	NA	NA
8	10	Finals	1/24/2025	8	6:00pm	17:07	No Ambient light	24/28	Try to eliminate ambient light from bottom of Night Skylights	No	NA	NA	0.3	NA	0.2
9	9	Finals	1/23/2025	8	5:11pm	17:06	No Ambient light	12/24	Expand light hole in box as try to eliminate ambient light from bottom of Night Skylight	No	NA	NA	0.4	NA	NA
10	8	Finals	1/22/2025	3	5:15pm	17:05	No Ambient light	NA/17	Try to eliminate ambient light from bottom of Night Skylights	No	NA	NA	0.2	NA	NA
11	7	Finals	1/21/2025	6	5:00pm	17:04	All Sun	13/NA	Try to deploy Phluo to Small Night Skylight	Yes: 4:20am	NA	NA	0.6	NA	0.2
12	6	Finals	1/16/2025	7	5:15pm	16:58	All Sun	22/NA	Establish baseline	Yes: 12:25am	2.8	2.7	0.4	0.4	NA
13	5	Screening	12/23/2024	7	4:45pm	16:38	50% Sun / 50% Shade	9/28	Try for full day of charging in full sun & 12 hours of light monitoring	Yes: 2:30am	4	4.3	NA	NA	NA
14	4	Screening	12/17/2024	4	6:07pm	16:34	All Sun	NA/NA	Compare only 4 hours of charging to 8 hours in prior test	No	0.65	0.7	NA	NA	NA
15	3	Screening	12/15/2024	8.5	6:30pm	16:33	All Sun	NA/NA	Tried long charge period but did not know the light degraded so quickly after dark.	Yes: 8:30pm, 10:25pm, 1am, 3:10am, 4:30am	0.4	0.4	NA	NA	NA
16	2	Screening	12/13/2024	2	4:30pm	16:32	All Sun	33/NA	Tried units with short charge period.	No	4.5	5.3	NA	NA	NA
17	1	Screening	12/12/2024	8	4:45pm	16:32	50% Sun / 50% Shade	32/NA	Learned importance of height of light sensor	No	Measurements done from 31" height so not useful.				

	A	B	C	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF
1						~4 Hours After Sunset Reading (Lux; with sensor 1.6 cm above light source)								~12 Hours After Sunset Reading (Lux; with sensor 1.6 cm above light source)				
2	ID	Testing Phase	Date	Measure-ment Time	# Hours from Sunset to Measure-ment Time	Honey-comb	Phluo	Large Night Skylight	Small Night Skylight	Modified Small Night Skylight with Phluo on back		Measure-ment Time	# Hours from Sunset to Measure-ment Time	Honey-comb	Phluo	Large Night Skylight	Small Night Skylight	Modified Small Night Skylight with Phluo on back
3	15	Finals	1/29/2025	21:15	4:02	0.1	0.1	0.05	0.05	NA		29:20:00	12:07	0.01	0.01	0.01	0.01	NA
4	14	Finals	1/28/2025	21:00	3:48	0.1	0.1	NA	NA	NA		29:15:00	12:03	0.01	0.01	NA	NA	NA
5	13	Finals	1/27/2025	20:20	3:09	0.2	0.1	NA	NA	NA		31:30:00	14:19	0	0	NA	NA	NA
6	12	Finals	1/26/2025	20:20	3:10	0.25	0.15	0.05	0	NA		28:40:00	11:30	0.01	0.01	0	0	NA
7	11	Finals	1/25/2025	Not tested								Not tested						
8	10	Finals	1/24/2025	Not tested								Not tested						
9	9	Finals	1/23/2025	20:37	3:31	NA	NA	0.02	NA	NA		30:30:00	13:24	NA	NA	0.02	NA	NA
10	8	Finals	1/22/2025	Not tested								Not tested						
11	7	Finals	1/21/2025	21:00	3:56	NA	NA	0.05	NA	0		29:30:00	12:26	NA	NA	0.01	NA	0.01
12	6	Finals	1/16/2025	20:35	3:37	0.2	0.1	0.1	0.05	NA		29:30:00	12:32	0.01	0.01	0.01	0.01	NA
13	5	Screening	12/23/2024	22:00	5:22	0.15	0.1	NA	NA	NA		30:40:00	14:02	0.01	0.01	NA	NA	NA
14	4	Screening	12/17/2024	20:35	4:01	0.2	0.1	NA	NA	NA		Not tested						
15	3	Screening	12/15/2024	20:30	3:57	0.25	0.15	NA	NA	NA		31:30:00	14:57	0.01	0.01	NA	NA	NA
16	2	Screening	12/13/2024	20:30	3:58	0.1	0.1	NA	NA	NA		Not tested						
17	1	Screening	12/12/2024	Not tested								Not tested						