An Integrated, Evidence-Based Approach to Transitioning to Operations: Specifications for Future Replacement Lights on ISS

Lauren Leveton, George Brainard, Alexandra Whitmire, Alan Kubey, Jim Maida, Charles Bowen, Smith Johnston

Replacement Lighting for the International Space Station

The International Space Station (ISS) currently uses General Luminaire Assemblies (GLAs) as its primary light source. These GLAs are composed of fluorescent lighting and are integrated into the electrical system on Station. Seventy seven of these units are distributed throughout the vehicle, and many of the lights, having reached their lifespan, are no longer functional; while backup panels are available on orbit, it is anticipated that the supplies of fluorescents on the station will be exhausted by 2015.

The ISS vehicle office is therefore preparing to replace all of the GLAs, with Solid State Light Assemblies (SSLAs) composed of white Light Emitting Diodes (LEDs). In the Spring of 2010, an announcement for the replacement lights was released. The announcement specified that proposed lighting systems should use LED technology, given certain power draw restrictions and no changes to how the lights are currently controlled (a central on/off switch per node, and a dial to turn on/off and increase brightness on each lighting unit). The replacement lights are to follow current specifications for brightness levels (lux) and color temperature (degrees Kelvin, or K).

Reportedly, the lighting on orbit is dim and suboptimal. The average brightness of the lights (given all lights within a node are operational) is 291 lux; by comparison, recommended office lighting ranges from 200 to 500 lux, and daylight ranges on a typical overcast day, consists of 10,000 to 25,000 lux. Representatives from NASA Behavioral Health and Performance Element (BHP) and Human Factors and Habitability identified that maintaining current brightness levels limits visual acuity, work space, and the use of light as a countermeasure for improving circadian entrainment, hastening phase shifting, evoking acute alertness and enhancing performance. Revised lighting specifications are therefore needed to optimize the replacement lights for the ISS.

Enhanced Brightness for Visual Acuity and Workspace

Brightness levels vary throughout the eight nodes on the ISS. Tasks requiring high visibility therefore, are limited to the more brightly light areas on the station. Allowing for an increased maximum brightness of all the units will permit high illumination tasks such as precision inspection and maintenance, and medical tasks such as examination of the eye, suturing, and test tube intubation, to be performed throughout the vehicle. Based on expert analysis, a recommendation was made to enhance the replacement lights so that they are capable of producing an average brightness level of 3200 lux (from current average of 291 lux). Additionally, each light should be dimmable so that brightness can be adjusted as needed.

Enhanced Brightness for Circadian Entrainment and Phase Shifting

There are additional benefits to crew safety, health and performance to be gained from enhanced lighting system. Human health risks – particularly the risk of performance errors due to fatigue resulting from sleep loss, circadian desynchronization, extended wakefulness and work overload- can also be mitigated.

Due to operational constraints, ISS crew members regularly endure phase shifts to their work/rest schedules. As a result, critical operation tasks must sometimes be performed during the subjective night, and sleep must be attained during the subjective day. Reduced sleep duration is a common outcome of this scenario. Objective evidence from Shuttle missions (ISS data collection is currently ongoing) reveals that the average total nightly sleep duration in flight is around 6 hours (Barger and Czeisler, 2008). *G*round studies clearly demonstrate that sleep in quantities as experienced by astronauts leads to lapses of attention equivalent to those seen after one night's total sleep deprivation (Van Dongen, Dinges et al., 2003; Belenky et al., 2003). Not surprisingly, sleep medications are used as a primary mitigation strategy in space (Putcha et al.,1999; Barger and Czeisler, 2009).

As demonstrated in numerous laboratory investigations, enhanced brightness allows for a non-pharmaceutical countermeasure for improving circadian entrainment, hastening phase shifting, evoking acute alertness, and enhancing performance (Riemersma-van der Lek, et al., 2008; Phipps-Nelson et al., 2003; Zeitzer et al., 2000; Cajochen et al., 2000; Steward et al., 1995).

Flexible Spectral Power Distribution

Lights are typically made up of one spectral power distribution (SPD) which characterizes the radiant power emitted by the source at each wavelength or band of wavelengths over the visible region (380 to 760 nanometer wavelengths, or nm). The planned replacement lights for the ISS are to include one SPD.

Lights equipped with multiple spectral power distributions allow for <u>an even more </u>potent countermeasure. Research has demonstrated that specific wavelengths, at certain times of day, can elicit neurobehavioral outcomes. For example, monochromatic blue light (~470 mm) is more effective than white light for phase shifting, melatonin suppression, and increasing alertness and performance (Brainard et al., 2001; Lockley et al., 2003, 2006), while recent evidence indicates monochromatic green light may be more effective than blue under dim light conditions (Gooley et al., 2010). Additionally, polychromatic light – light that appears white --

that is enriched in the blue portion of the spectrum is more potent biologically than typical white fluorescent light (Brainard et al., 2010).

An ideal lighting system would allow crew members to enrich lights with specific wavelengths based on the desired outcome. A spectrum that de-emphasizes wavelengths of light (~470nm) can be used in the off-duty, pre-bedtime period to promote sleep onset while a spectrum that emphasizes wavelengths of light (~470 nm) could be used to promote alertness (Figures 1 and 2). A range of spectrums in one lighting unit, therefore, allows for multiple applications of light in the same place. Recommended SPDs are being prepared for the planned ISS replacement lights.

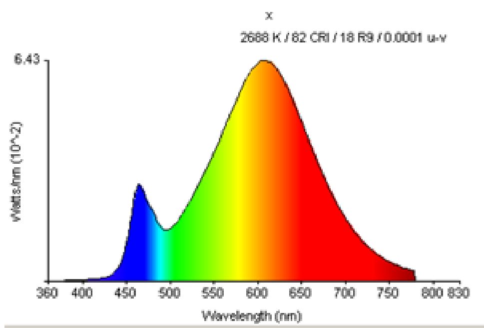

Figure 1: Pre-Sleep (de-emphasize blue)

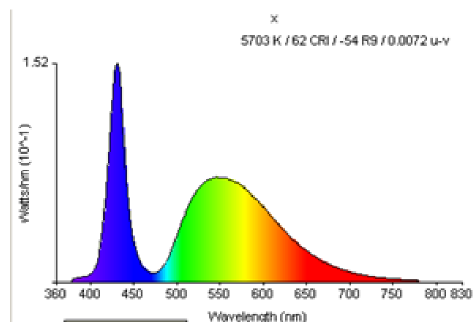

Figure 2: Awakening (emphasize blue)

Operational Use of Enhanced LEDs on ISS

The lighting specifications – increased brightness capability (lux) and multiple spectral power distributions (nm) – provided are based on scientific and evidence, and will optimize light as an inflight countermeasure. One must, however, consider the use of these lights in the operational environment. As previously mentioned, no changes to the control of the lights from the way they are currently controlled, can be made: if crew members therefore want to dim brightness or enrich wavelengths, in the current scenario they must manually change each light within a node. As a result, an integrated wireless solution is being developed through which a remote device could control each of the various LEDs outputs between 0 and 100%, and would allow for fine spectrum (color mixing) and lux level adjustment, in addition to logging of lighting spectrums over time. Other aspects for making the lights usable in the operational environment would include a hard three-way toggle switching the light's spectrum between two preset countermeasure spectrums ("Entrainment CM" and "Pre-sleep CM") and a preset for supporting crewmember vision.

Acknowledgement of Participants

BHP would like to thank Laura Barger, PhD, Steve Lockley, PhD, and Chuck Czeisler, MD, PhD for their input on this effort. Additional participation from Charlie Marshik, Adam Schlesinger, Laura Duvall, and Tom Sullivan, PhD (NASA JSC); Raymond Wheeler, PhD (NASA KSC); Erin Evans, PhD and Elizabeth Klerman, MD, PhD of Harvard Medical School; Ken Wright, PhD (University of Colorado); Robert Soler (Lighting Science Group Corp.) and Yuming Chen and Badruddin Khaled (CREE).