International Space Station (ISS) Crewmember's Noise Exposures from 2015 to Present

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Noise has been an enduring environmental physical hazard that has challenged the U.S. space programs since before the Apollo program. During long-duration missions on the International Space Station (ISS), noise exposures from onboard equipment and crew activities are posing concerns for human factors, human performance and crew health. According to acoustic dosimetry data collected to date, NASA's stringent noise hazard exposure limits; (based on World Health Organization guidelines), have been exceeded approximately 45% of the time since ISS increment 17 (2008), with undefined impacts on crew. This measure does not take into account the effects of any hearing protection devices (HPDs) worn by the crew, as the dosimeter microphones are attached to the crew's collars. The crew are instructed to wear HPDs as an operational control when exposed to known hazardous noise sources, and when they feel the noise levels are high. It is still crucial to control noise aboard ISS to acceptable noise levels during the work-time period, and also to provide a restful sleep environment during the sleep-time period. The purpose of this paper is to provide an update on crew noise exposure monitoring data collected since May 2015 (ISS Increment 43) and also to compare data to previous reporting periods. A review of NASA's noise level constraints flight rule will be briefly described, as well as our Noise Exposure Estimation Tool and Noise Hazard Inventory implementation. Future acoustics research will aim to relate ISS noise exposures to auditory and non-auditory health effects, especially how acoustic conditions can affect hearing sensitivity, human performance, sleep, and crew health on the ISS.

Nomenclature

CQ	=	*crew quarter*
dB	=	*decibel*
dBA	=	*A-weighted decibel*
BME	=	*Biomedical Engineer*
ER	=	*exchange rate*
GMT	=	*Greenwich Mean Time*
HPD	=	*hearing protective device*
IMV	=	*inter-module ventilation*
Inc.	=	*ISS Increment*
ISS	=	*International Space Station*
JEM	=	*Japanese Experiment Module*
JSC	=	*Johnson Space Center*
$L_{A,24}$	=	*24-hour equivalent noise exposure level*
$L_{A,PK}$	=	*highest instantaneous noise level*
$L_{A,T}$	=	*noise exposure level, actual crew wear times, T*
L_{EQ}	=	*equivalent noise exposure level*
L_{EQ8}	=	*equivalent noise exposure level (sleep-time period, 8 hours)*
L_{EQ16}	=	*equivalent noise exposure level (work period, 16 hours)*

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L_{EQ24} = *equivalent noise exposure level (full-day, 24 hours)*
Lnight = *night noise exposure*
NEET = *Noise Exposure Estimation Tool*
NIOSH = *National Institute of Occupational Safety and Health*
NHI = *Noise Hazard Inventory*
OSHA = *Occupational Safety and Health Administration*
Rtime = *Run time (hour:min)*
SLM = *sound level meter*
TeSS = *Temporary Early Sleep Station*
WHO = *World Health Organization*

I. Introduction

THIS paper presents a status update of the International Space Station (ISS) noise exposure monitoring and hearing conservation strategies previously presented,[1-3] as well as a summary and an assessment of the acoustic dosimeter data collected since 2015. It includes crew-worn noise exposure monitoring data collected during the work- (L_{EQ16}) and sleep- (L_{EQ8}) periods and environmental noise exposure data, both collected on ISS. General details and descriptions of ISS and its modules are presented elsewhere.[1-3] Crew-worn and environmental monitoring is currently performed by the trained crewmembers onboard ISS, with technical support provided by ground personnel.

Acoustic monitoring measurements made onboard the ISS are performed and the data is used to ensure a safe working and living environment for the crew, as well as to determine when actions are required in order to reduce the noise onboard the ISS. All acoustic requirements are documented in the Medical Operations Requirements Document,[4] the Medical Requirements Integration Document,[5] the Generic Groundrules and Constraints Document,[6,7] the Increment Definitions and Requirements Document[8] and the Noise Level Constraint ISS Flight Rule (JSC Flight Rule B13-152).[9] The ISS Noise Level Constraints Flight Rule is based on 16-hour crew-worn work-period noise exposure levels (L_{EQ16}) and 8-hour crew-worn sleep-period noise exposure levels (L_{EQ8}) measured by the ISS acoustic dosimeters. This flight rule sets forth the hearing conservation standards according to the type of activity and duration (16 hours of crew work period and 8 hours of sleep period) and is based on noise exposure levels measured and calculated (from sound levels and corresponding exposure durations) using a 3-dB equal energy exchange rate (ER) and the World Health Organization (WHO) noise guidelines.[10] According to the WHO, for ground conditions, "Hearing loss is not expected to occur at L_{EQ}, 8hr levels of 75 dBA or lower, even for prolonged occupational noise exposures." This level corresponds to an L_{EQ16}, 16hr of 72 dBA or lower using the internationally accepted 3-dB equal energy ER. In addition, the WHO states, "It is expected that environmental and leisure-time noise with an L_{EQ24}, 24hr of 70 dBA or lower will not cause hearing impairment in the large majority of people, even after a lifetime exposure." This L_{EQ24}, 24hr level of 70 dBA corresponds to an L_{EQ16}, 16hr "work" level of 72 dBA and with an L_{EQ8}, 8hr "sleep" level of 62 dBA using the 3-dB ER. In order for the Acoustics and Audiology offices at Johnson Space Center (JSC) to assess the noise levels and to take the necessary protective measures, a Noise Hazard Inventory (NHI) was developed and provided to the ISS Mission for use in conjunction with this flight rule. The NHI was first implemented during ISS increment 36 (July 2013). The Flight Surgeons/Biomedical Engineers (BMEs) are in charge of monitoring compliance with these rules. The JSC Acoustics Office provides the increment-specific NHI for each ISS increment. The NHI is a database of sound pressure level data compiled from ground and on-orbit measurements of hardware that is used by crewmembers while working and living on ISS. The NHI provides a correlation between noise exposure and identified activities as well as locations to allow informed recommendations for when the crew should wear hearing protection. The noise exposure and the needs for HPDs was determined by the Noise Exposure Estimation Tool. This correlation is based on a calculated 16-hour work-period noise exposure level. All currently-provided hearing protective devices (HPDs) are appropriate for use and reduce noise exposure sufficiently. In addition, the data obtained from the noise measurements is analyzed to help determine sources of excessive noise and to indicate the need for future noise mitigations. The NHI reduces the risk for noise-induced hearing loss, and helps improve voice communications by avoiding unnecessarily mandated hearing protection use. The NHI is used for implementing the acoustic flight rule that is based on a "task-based" hearing conservation approach. The plan is to collect time-specific crew location and activity information during the nominal bimonthly crew acoustic dosimetry session. Any crew activity or task with noise levels exceeding 60 dBA that is not already covered under specific crew procedures, is included in the NHI to help mitigate current and future (long-term) crew noise exposure risks. Use of appropriate HPDs may also be required as a result of the noise exposure analysis, including exposure sound levels and durations. If the L_{EQ16} is higher than 72 dBA, then the crewmembers are directed to wear appropriate HPDs during the activities where high noise exposure levels are present. These activities and the noise exposure levels are identified in the increment-specific NHI. However, if the L_{EQ16} is above 60 dBA, the flight surgeon recommends to the affected crewmember use of appropriate HPDs based on the individual needs of the crewmember and the level and duration of the noise exposure. These activities and the noise exposure levels are also identified in the increment-specific NHI. Adherence to these guidelines should keep the sound energy levels to which the ear is exposed at an acceptable level. In order to keep continuous background levels low, NASA and the Johnson Space Center's Acoustics Office have developed and implemented acoustic requirements that must be met for hardware and payloads to be certified for spaceflight and operation on ISS.[11] Along with acoustic requirements, methods and practices used on ISS to control noise levels may also include verification of requirements, noise control implemented during the design phase of the hardware, analyses, testing and on-orbit monitoring. Examples of hardware noise control are discussed elsewhere.[12-15]

A total of three acoustic dosimeters are onboard ISS at all times. The acoustic dosimeter currently being used for monitoring ISS noise exposures is a Quest model NoisePro DLX-1®. Detailed explanations on the dosimeter's features and capabilities are documented in Ref. 1. This instrument is used to obtain crew-worn and static acoustic dosimetry measurements. To obtain crew-worn (personal) noise exposure data, the crewmembers wear the acoustic dosimeters for a continuous 24-hour period (including during the sleep-time period), to measure typical noise exposures as they perform nominal tasks and move throughout various locations on ISS, as well as in their respective sleeping quarters. The device is stored in a pocket or clipped to the crewmember's clothing and its microphone is clipped on the crewmember's collar or lapel so that it is in close proximity to the ear. For environmental noise exposure data, the acoustic dosimeter is then placed at specific fixed (static) locations on ISS. Placing the dosimeter in these designated locations has helped characterize the internal acoustic environment of ISS, and assisted in the implementation of effective countermeasures which reduced or eliminated crew exposure to high noise levels and the need to don HPDs. All crewmembers are trained, prior to flight, in acoustic dosimeter measurement techniques and proper use of HPDs. This training includes nominal operation of the acoustic dosimeter hardware, software handling and operational and malfunction procedures, as well as options for HPD use on ISS.

II. Data and Analysis

Acoustic dosimetry data were collected from crew-worn and static location measurements. During nominal sampling days and when using three acoustic dosimeters, the activity was divided into four days; crew-worn measurements for all six crewmembers (days 1, 2), static measurements (day 3), and data download activity (day 4). These activities are performed every other month. For the crew-worn session of the activity, the crewmember dons the acoustic dosimeter and starts the measurement before breakfast during the day of the planned activity. The crew-worn session concludes immediately before post-sleep activities the following day. The crew-worn session includes day-time (16-hours) and sleep-time (8-hours) periods. For the static measurement session, the crewmember deploys the acoustic dosimeters at predetermined locations. This activity is normally performed during the 3rd day of the acoustic dosimetry activity. The static locations may include specific areas in the modules or in the vicinity of specific hardware for conducting assessments and evaluations of its performance, e.g. motorized exercise equipment (treadmill). These locations are preselected by the JSC Acoustics Office in coordination with our Russian acoustic counterparts and are rotated throughout the ISS modules for trending purposes. During this reporting period (ISS increments 43 through 51; 2015-2017), several issues (hardware problems and crew procedure errors) were encountered during the acoustic dosimetry sessions. These issues resulted in 18% and 28% of data loss during this timeframe of crew-worn and static (fixed) measurements, respectively. We also lost the operation of one of the dosimeters (leaving only two dosimeters operational) which extended the acoustic dosimetry activity one extra day, from four to five days (increasing crew time by 60 minutes per increment), resulting in an operational impact. Replacement acoustic dosimeters (3 new units) are scheduled to be launched and delivered to ISS during spring 2017. The current plan is to keep one of the two old acoustic dosimeters on ISS as a spare unit just in case we come across any hardware malfunctions on the new replacement units.

After completing the crew-worn and static measurements, the data is then transferred from all dosimeters to the Space Station Computer and downlinked via the Orbital Communications Adapter and delivered to the JSC Acoustics Office for analysis and reporting. The following paragraphs will discuss the crew-worn and static location measurements, along with the analysis of the data collected during the time period May 2015 through April 2017.

A. Crew-worn measurement

The crewmembers donned acoustic dosimeters before breakfast on the day of the acoustic dosimetry activity for the duration of 24 hours to record the work-day (L_{EQ16}) and sleep- (L_{EQ8}) period data. Post-sleep crew-worn data were deleted from the analysis, reducing the total duration time period to 24-hours or less. An example of the equivalent noise exposure levels (L_{EQ}) along with other data collected from the acoustic dosimeters are shown in Table 1. Since the approval of the revised Noise Level Constraint ISS Flight Rule,[9] ISS noise exposure levels have been measured using a 3-dB time-intensity ER, consistent with criteria recommended by the National Institute of Occupational Safety and Health (NIOSH)[16] and the U.S. Department of Defense, and it has also been adopted internationally for use in hearing conservation programs.[17] In this paper, all data, including the plots, will be presented using the 3-dB ER unless otherwise stated.

An example of a crew-worn acoustic dosimeter logged data graph can be seen in Fig. 1. The graph has been divided into the work- and sleep-periods. The hazard level (85 dBA), the 16-hour L_{EQ} limit (72 dBA) – crew directed to wear HPD, and the 60 dBA limit – crew recommended to wear HPD; have been identified in the graph. For this particular dataset, the equivalent noise exposure level (L_{EQ}) during the work-period was measured at 74.5 dBA. Based on the Noise Level Constraint ISS Flight Rule, this crewmember was required to don HPD during crew activities since the levels were above the 16-hr L_{EQ} limit (72 dBA). However, the use of HPDs was also required since the L_{EQ} was above the hazard level for the sixth and eleventh hour during the work-time period. Also, the flight surgeon can always recommend to don HPD whenever the levels go above 60 dBA based on the individual needs of the crewmember and the level and duration of the noise exposure. During the sleep-time period, the equivalent noise exposure level was 50.3 dBA, just above the sleep disturbance level (50 dBA) but below the sleep level for adequate hearing rest (62 dBA).

Table 1. Crew-Worn Acoustic Dosimetry Data (Example).
L_{EQ} indicates the equivalent noise exposure level during the work and sleep-time periods. $L_{A,PK}$ indicates the highest instantaneous noise level measured during the measurement period, independently of the slow or fast response that the unit is set for and is averaged into the L_{EQ}. Rtime represents the run time, hrs:minutes (exposure time).

Activity	Crewmember	S/N	Activation Time	$L_{A,PK}$ [dB]	L_{EQ} [dBA]	Rtime [h:min]	Location
Work-Time Period	A	1025	8:10 AM	130.0	70.1	14:45	ISS Modules
	B	1026	8:11 AM	122.6	68.3	14:05	ISS Modules
Sleep-Time Period	A	1025	10:56 PM	110.3	52.8	8:06	Sleep Station
	B	1026	10:17 PM	119.0	47.5	8:10	Sleep Station
Work-Time Period	C	1027	8:12 AM	120.6	66.8	13:19	ISS Modules
	D	1025	7:50 AM	121.5	73.7	13:27	ISS Modules
Sleep-Time Period	C	1027	9:32 PM	111.5	57.3	9:56	Sleep Station
	D	1025	9:18 PM	110.2	48.7	9:11	Sleep Station

SOURCE: Acoustic dosimeter data collected on August 2016.

Crew-worn acoustic dosimetry data on ISS have been collected since Increment 1 (see Fig. 2). These data were based on all crewmembers who were a long-duration resident in ISS since November 2001. Based on all of the data collected to date, 32% of crewmembers' L_{EQ24} were above 70 dBA, which may have required use of hearing protection according to the flight rule. However, since Increment 21 there has been a reduction (8%) in crewmembers' L_{EQ24} levels above 70 dBA. Nevertheless, for this reporting period, from Increments 43 through 51 (shaded yellow area), 21% of crewmembers' L_{EQ24} were above 70 dBA (fewer than previously reported). This decrease in noise exposure levels was mostly due to the result of general improvements in acoustic levels on ISS as described in Ref. 12. These improvements include noise mitigation in the Russian Segment (e.g., installation of quiet fans, mufflers, etc.), as well as the addition of new quieter modules (e.g. Columbus Module, Japanese Experiment Module etc.) and crew sleeping quarters. However, crew activities and hardware conditions (e.g. clogged inter-module ventilation (IMV) fans) in ISS have elevated the noise levels during past increments. Stalled IMV fans, caused by dust clogging the fans, can be loud, approximately NC-60. These levels persist until the fans are cleaned. While stalled, the high noise levels

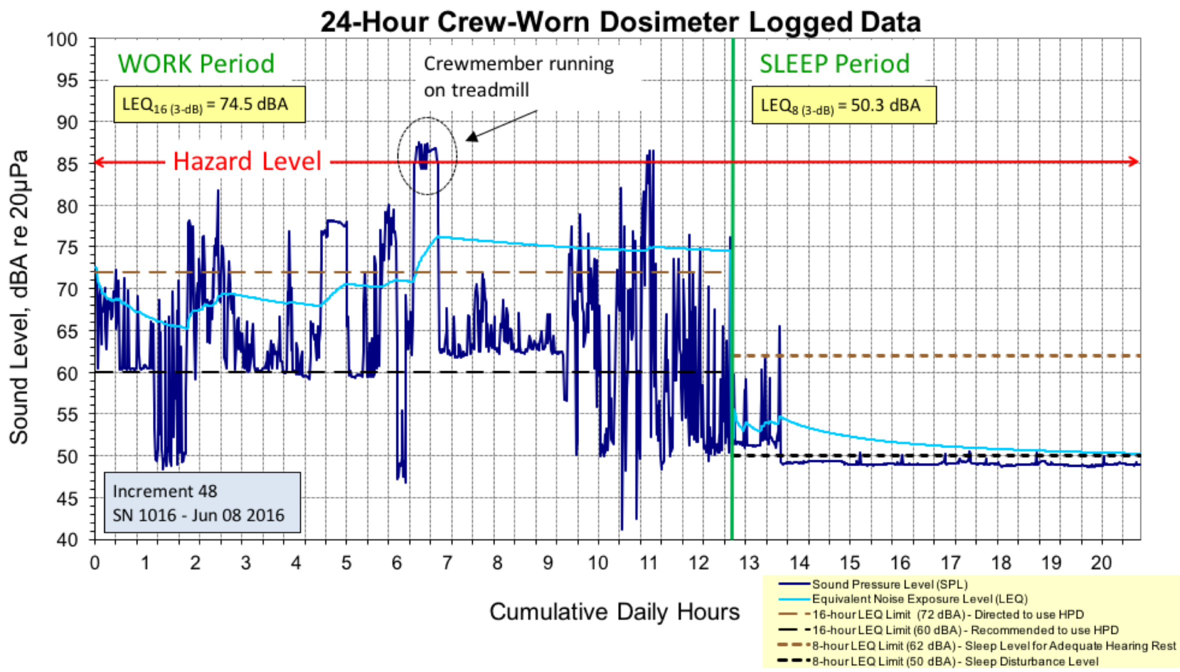

Figure 1. Crew-worn Acoustic Dosimeter Logged Data.
SOURCE: ISS Acoustic dosimeter data collected on June 2016, Increment 48.

increase the risks for degraded voice communications, and habitability (possible disruptions to crew sleep, interference with crew performance, etc.) . After the IMV fans were cleaned, noise levels returned back to nominal levels and these were verified during the next acoustic measurement activities, as described in Ref. 2.

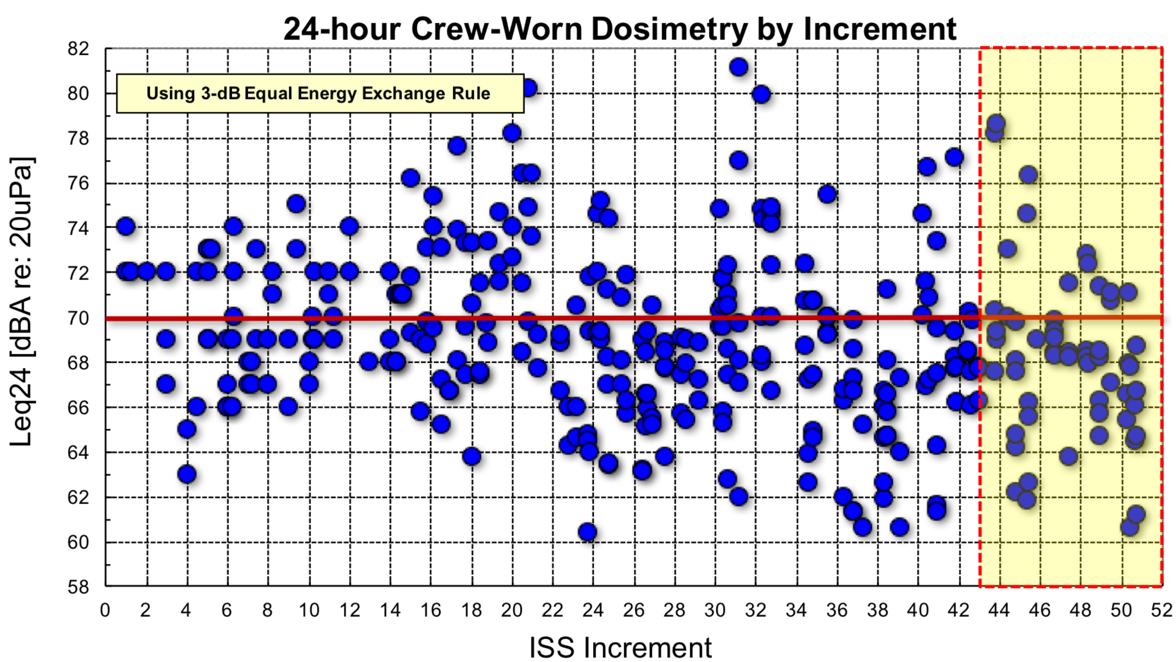

Figure 2. 24-Hour Crew-Worn Acoustic Dosimetry vs ISS Increment.
SOURCE: Acoustic dosimeter data collected from November 2001 (Inc. 1) through April 2017 (Inc. 51).

As previously reported, the noise exposure level for the work-time period was mostly dependent on where the crewmembers spent most of their time and what activities or tasks they were performing.[1-3] A crewmember can either work in the Russian segment modules or in the U.S. segment modules (see Figs. 3 and 4 for a data distribution of L_{EQ16} during work hours). The data showed that the crewmembers who worked most of their time in the Russian segment were initially exposed to higher noise levels than crewmembers who worked in the U.S. segment. However, their L_{EQ16} levels have been decreasing when compared to previous ISS increments with the exception of this reporting period (Inc. 43 – 51) when levels were slightly elevated.

For crewmembers who have spent most of their time working in the U.S. segment modules, levels have remained constant as compared to the previously-reported levels (Inc. 37-42). Recently reported levels (Inc. 43-51) have the same average as previously-reported average level (Inc. 37-42) but with a narrower noise data range. Use of hearing

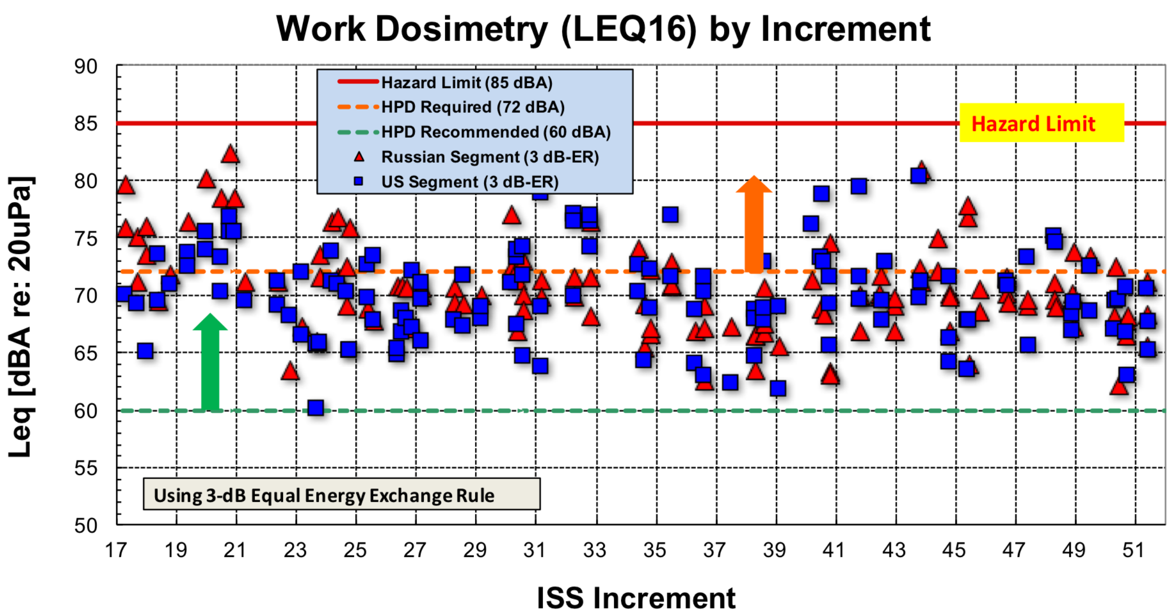

Figure 3. Distribution of L_{EQ16} during work hours by location.
SOURCE: Acoustic dosimeter data collected from July 2008 (Inc. 17) through April 2017 (Inc. 51).

protection was always required to crewmembers when running (>10 mph) on the treadmills (e.g. Node 3), and when exposed to known high noise levels during crew activities or tasks. Nonetheless, hearing protection was always available to all crewmembers on ISS.

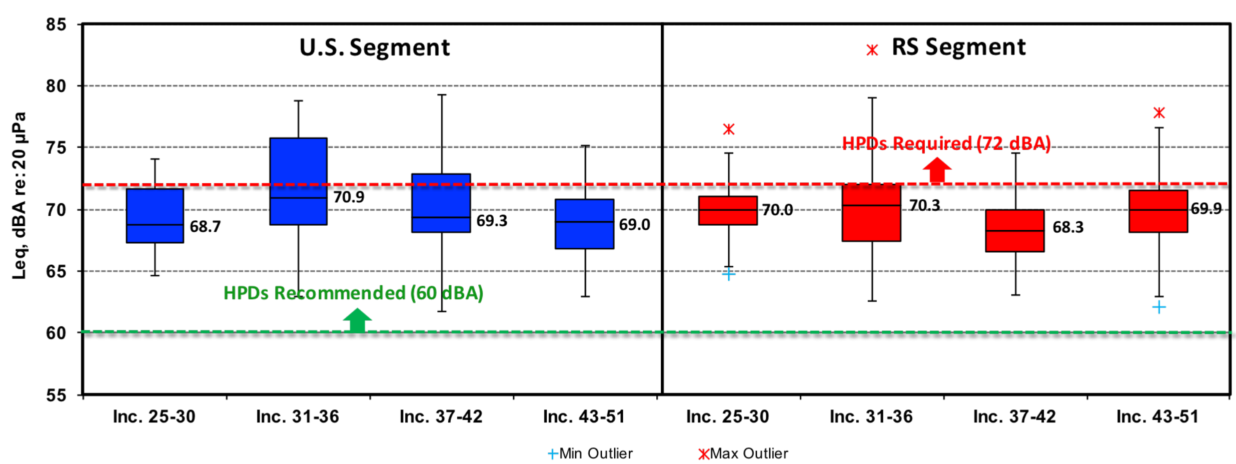

Figure 4. Time comparison of the distribution of L_{EQ16} during work hours in the US and RS segments.
SOURCE: Acoustic dosimeter data collected from October 2010 (Inc. 25) through April 2017 (Inc. 51).

The crew sleep stations were designed to provide a personal, private area for a crewmember to rest, sleep, and work and also for personal activities.[1] Currently there are a total of six permanent sleep stations: two Russian sleep stations (Port and Starboard kayutas) located in the Russian segment in the Service Module and the other four sleep stations (crew quarters) are located in the U.S. segment in Node 2. The ISS crew quarter (CQ) provided a quiet area for recovery (reduced acoustic stimulus to the ears) from daytime noise exposure levels. Noise levels in the Russian sleep stations (kayutas) have previously been a concern, but levels have decreased on the average by approximately 10 dBA since levels were first measured in November 2001.[1] For this reporting period (Inc. 43-51), L_{EQ8} have been measured above 62 dBA in the kayutas in four occasions during Increments 46, 47, 48 and 51 and for the first time in two occasions it was measured below 50 dBA. See Fig. 5. When compared to the previously reported levels (Inc.

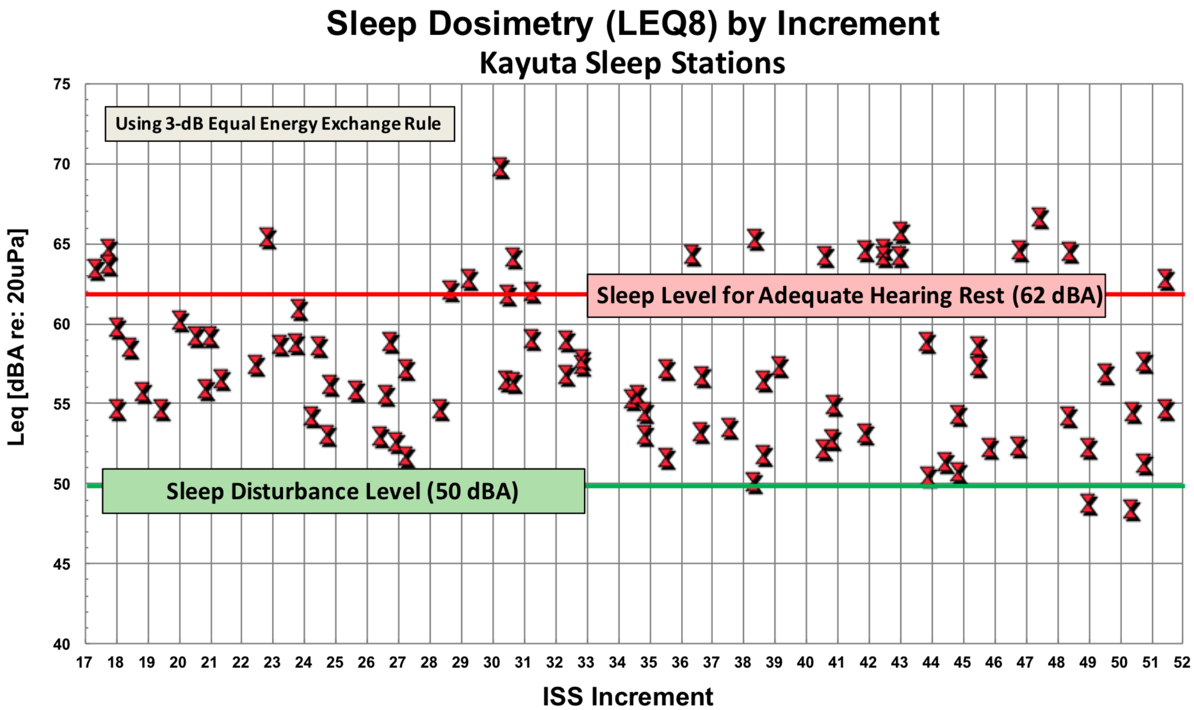

Figure 5. Sleep Dosimetry vs. ISS Increments (Russian Segment).
SOURCE: Acoustic dosimeter data collected from October 2010 (Inc. 17) through April 2017 (Inc. 51).

25-30, Inc. 31-36 and Inc. 37-42), the average sleep-time period noise levels (L_{EQ8}) in the kayutas (during the ISS increments 43-51) have continued to decrease (see Fig. 6).

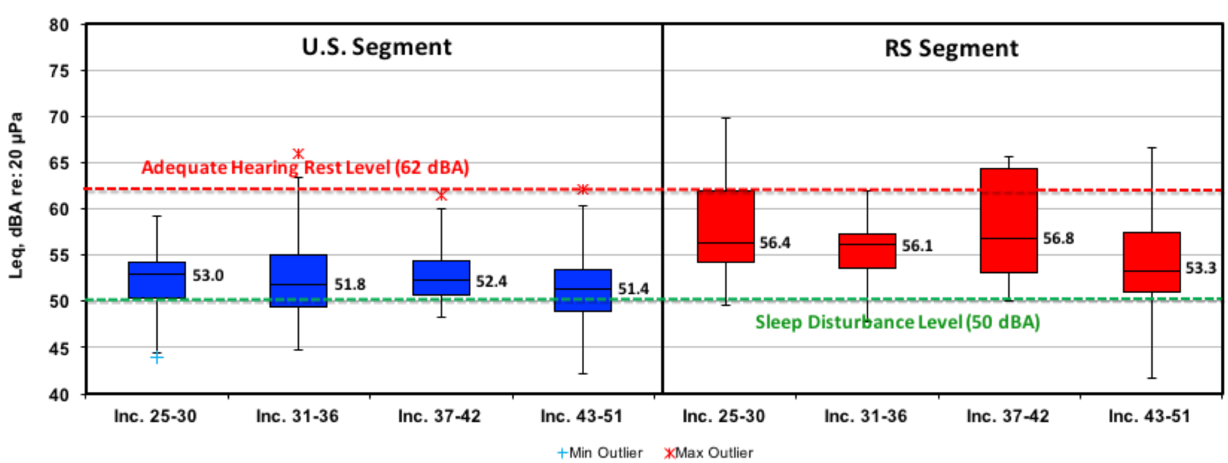

Figure 6. Time comparison of the distribution of L_{EQ8} during sleep time hours in the U.S. and RS segments.
SOURCE: Acoustic dosimeter data collected from October 2010 (Inc. 25) through April 2017 (Inc. 51).

The ISS crew's sleep-time noise exposure levels for CQs located in the U.S. segment are shown in Fig. 7. Overall, sleep-time noise levels in the permanent U.S. CQs have mostly remained below the adequate hearing rest level (62 dBA). When compared to the previously reported levels,[1-3] the current average sleep-time period noise levels (ISS increments 43-51) have remained statistically constant and lower than the previously reported sleep-time period noise exposure levels and also lower than the sleep stations (kayutas) located in the Russian segment (RS) (see Fig. 6). However, both the U.S. and Russian sleep stations are adequately quiet, when doors are closed to provide auditory

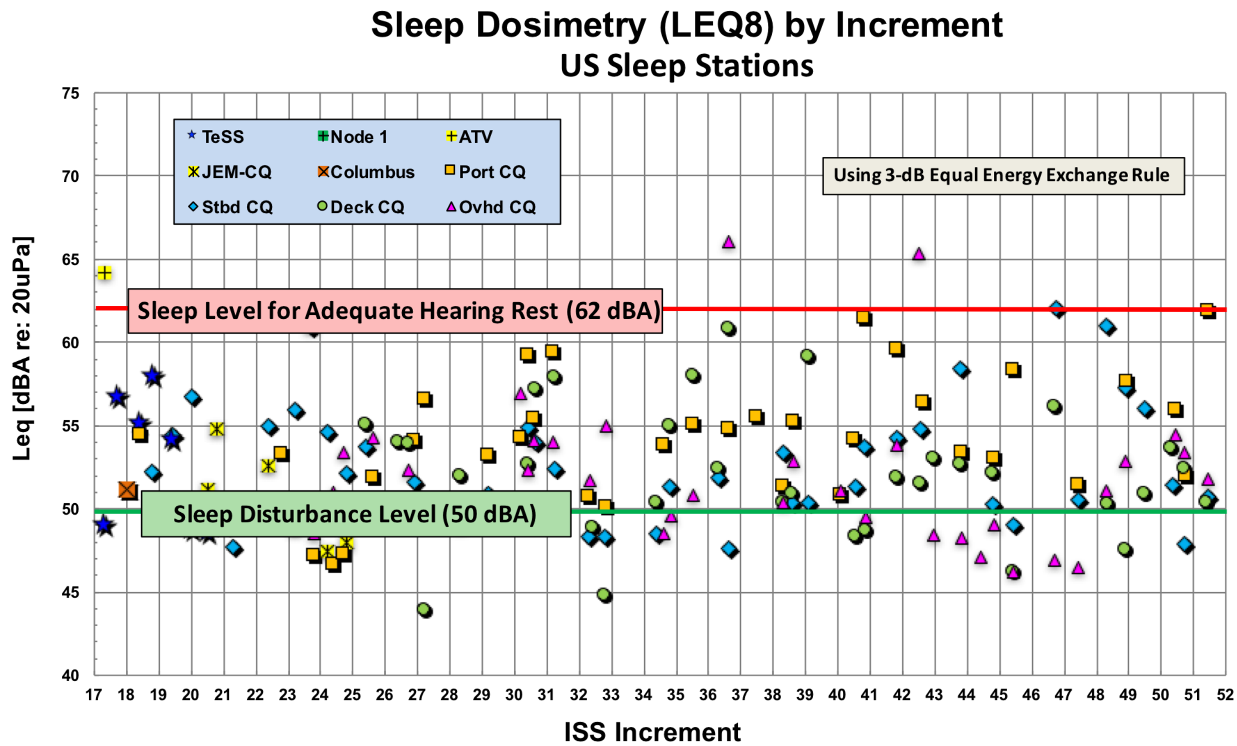

Figure 7. Sleep Dosimetry vs. ISS Increments (US Segment).
SOURCE: Acoustic dosimeter data collected from July 2008 (Inc. 17) through April 2017 (Inc. 51).

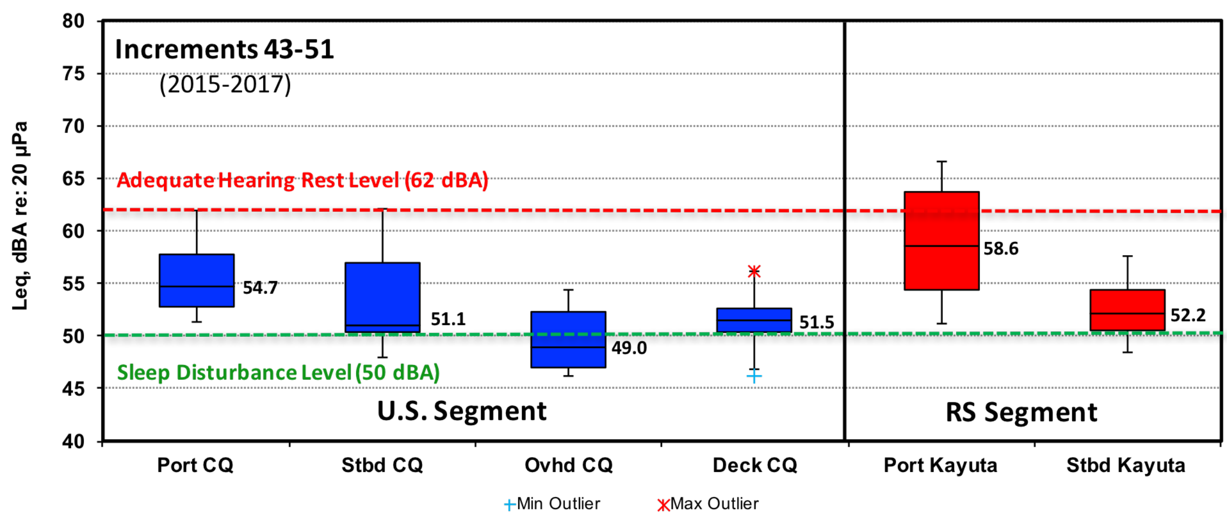

Figure 8. Distribution of L_{EQ8} during sleep hours by location.
SOURCE: Acoustic dosimeter data collected from May 2015 (Inc. 43) through April 2017 (Inc. 51).

rest, and do not increase the risk for hearing loss. However, the exceedances of the sleep requirements (U.S.: 49 dBA (L_{EQ8}) and Russian: 50 dBA (L_{EQ8})) are considered potentially disruptive to restful sleep. The WHO recommends a night noise exposure (L_{night}) value of 40 dBA or lower to be the target of the night noise guideline to protect the public.[18] However, WHO also recommends an L_{night} value of 55 dBA or lower as an interim target when the 40 dBA level cannot be initially met. Crew debriefs have indicated that crew sleep had not been affected by ISS sleep station noise levels. Different types and sizes of HPDs are always available to crewmembers on ISS, if needed. Noise exposure levels during the sleep period are very dependent on crew activities and preference, e.g. crew sleeping with the fan operating on high speed and or the crew sleeping with the sleep station door opened. When the sleep station door is opened, the module's environmental noise level can affect the levels inside the sleep station (impacting crew noise exposure).

When observing at the individual sleep stations for this reporting period (Inc. 43-51), the data showed that the equivalent noise exposure levels in the kayutas (in the Russian segment), were higher than the CQ noise levels located in the U.S. segment (Node 2). Figure 8 shows the data distribution of L_{EQ} levels during sleep hours. The levels indicated that the overhead CQ was the quietest sleep station in the U.S. segment and the starboard kayuta was the quietest in the Russian segment. But the port kayuta had levels above the adequate rest hearing level (62 dBA) whereas the U.S. sleep stations were all below 62 dBA. This difference could be due to sleep station's design features and also whether or not the crew sleep station's door was kept opened or closed during this sleep-time period due to crew preferences. Overall, the crew sleep stations provided a quiet area for recovery (reduced acoustic stimulus to the ears)

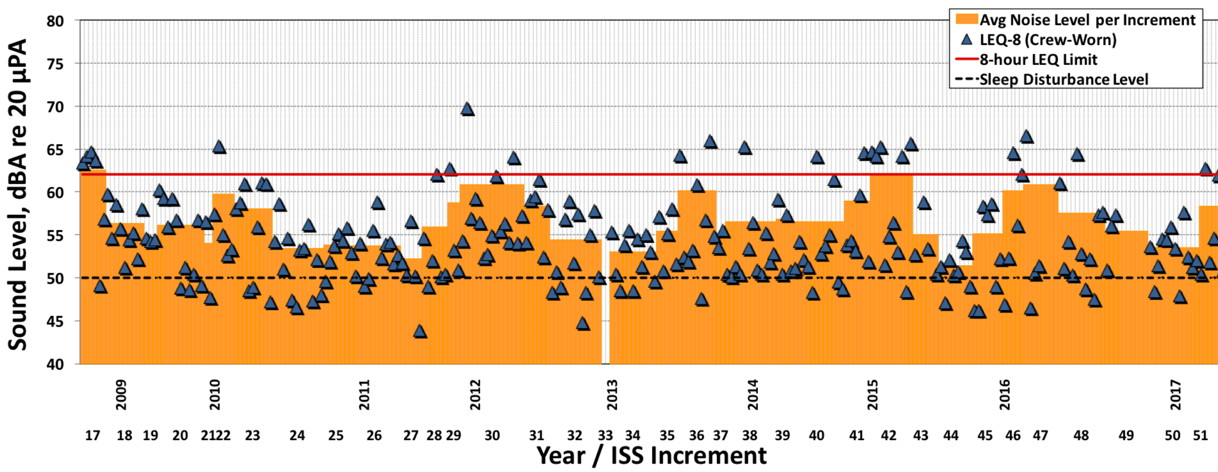

Figure 9. Distribution of L_{EQ8} during sleep-period hours.
SOURCE: Acoustic dosimeter data collected from July 2008 (Inc. 17) through April 2017 (Inc. 51).

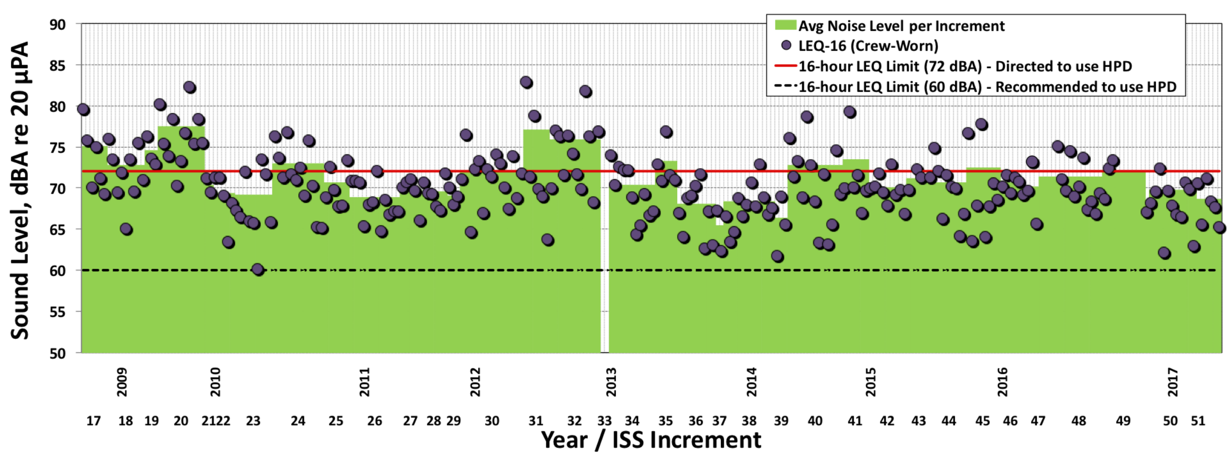

Figure 10. Distribution of L_{EQ16} during work-period hours.
SOURCE: Acoustic dosimeter data collected from July 2008 (Inc. 17) through April 2017 (Inc. 51).

from daytime noise exposure levels. The average noise exposure levels for the sleep-time period continue to remain below the adequate hearing rest level (62 dBA). See Fig. 9. This data includes all six sleep stations. However during this reporting period, four individual crewmembers' noise exposure levels were above the 8-hour L_{EQ} limit (62 dBA).

After reviewing the trend of the average work-time period noise exposure level data (combining U.S. and Russian crewmember's noise exposure data) for this reporting period, it was concluded that crew exposure noise levels have remained consistently stable and below the 16-hour L_{EQ} limit (72 dBA), with the exception of ISS increment 45 where the average level was slightly above the HPD required limit. (See Fig. 10). After an extensive review of the work period crew noise exposure data, we were able to identify approximately 35% of the noise sources that contributed to the crewmember's noise exposure levels when exposure levels were above the noise hazard level (85 dBA). The three main noise sources identified were: (1) running on treadmill at speeds greater than 10 mph or being near the treadmill when a crewmember is running at high speeds, (2) the ISS Waste Hygiene Compartment pump anomaly during increment 38 (see Ref. 3) and (3) exposure to high noise levels when working behind equipment panels in the Russian segment (Service Module). (See Figs. 11 and 12). From the unidentified events in the dataset, 56% are linked to U.S.

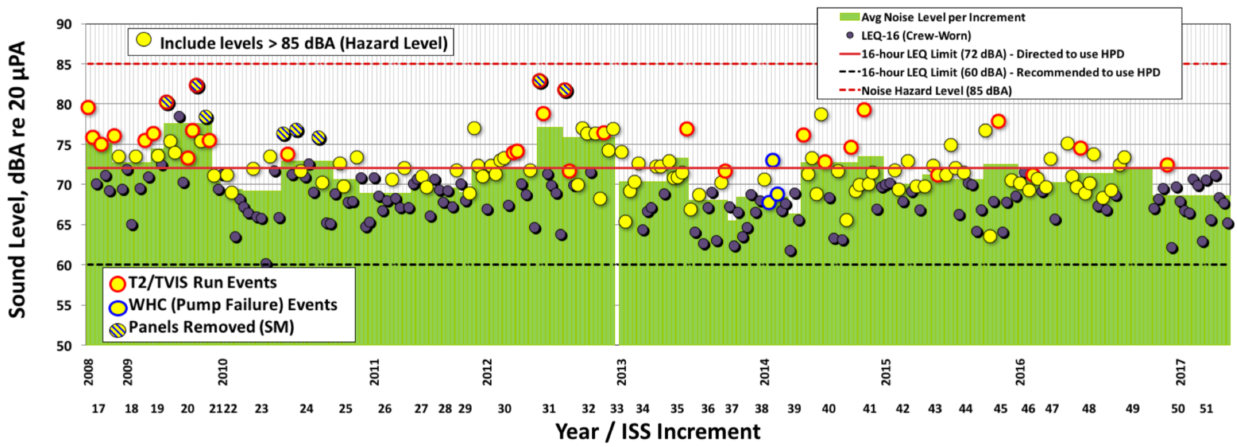

Figure 11. Distribution of L_{EQ16} during work-period hours (include levels above 85 dBA, Noise Hazard Level). SOURCE: Acoustic dosimeter data collected from July 2008 (Inc. 17) through April 2017 (Inc. 51).

crewmembers and 44% to Russian crewmembers. Continued efforts to better understand the acoustic environment on ISS are needed in order to reduce the noise exposure to our crewmembers on ISS.

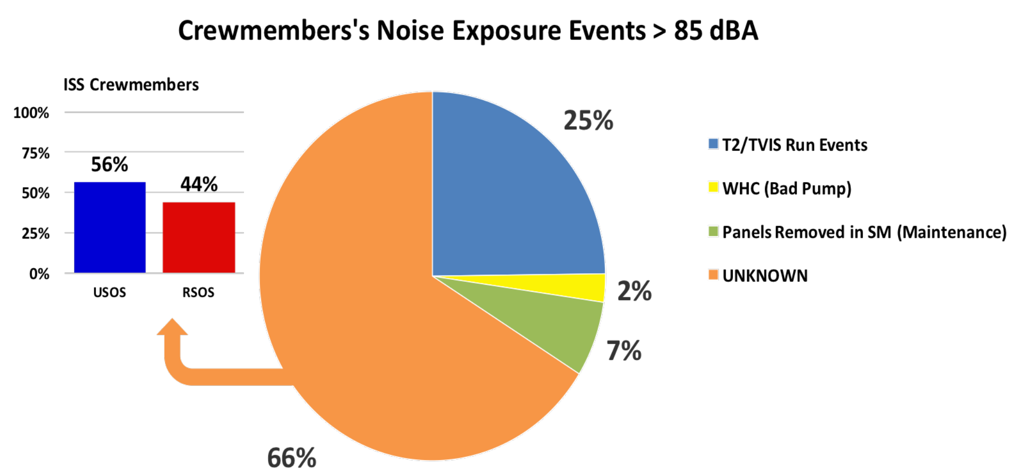

Figure 12. Distribution of noise exposure events during work-period hours (include levels above 85 dBA). SOURCE: Acoustic dosimeter data collected from July 2008 (Inc. 17) through April 2017 (Inc. 51).

According to acoustic dosimetry data collected to date, NASA's stringent noise hazard exposure limits; (based on WHO guidelines), have been exceeded approximately 45% of the time since ISS increment 17 (2008), with undefined impact to crew. This measure does not take into account the effects of any HPDs worn by the crew, as the dosimeter microphones are attached to the crew's collars. (See Fig. 13).

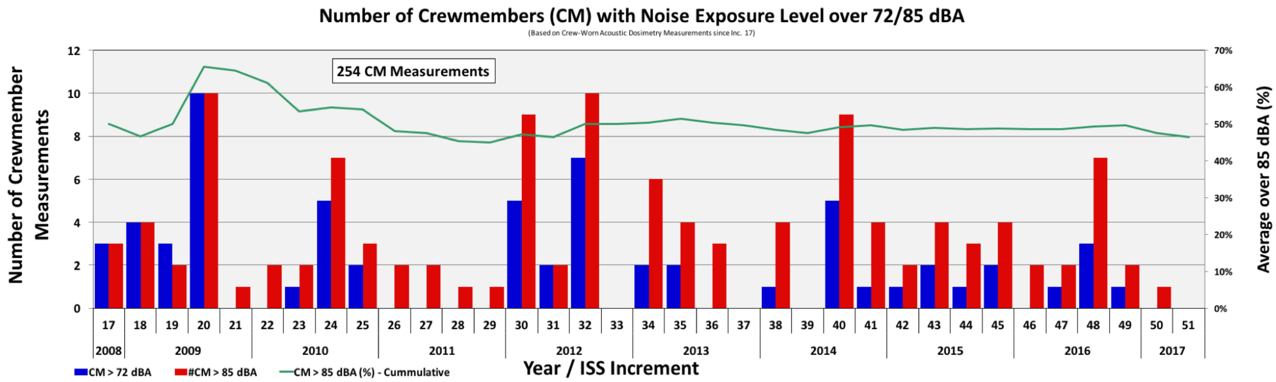

Figure 13. Acoustic Dosimeter Crew-Worn Measurement with Noise Exposure Level over 72/85 dBA
SOURCE: Acoustic dosimeter data collected from October 2010 (Inc. 17) through April 2017 (Inc. 51).

B. Static location measurement

After completing the 24-hour crew-worn measurements for all six crewmembers, the dosimeters were then deployed at predetermined locations for 24-hours for area monitoring. The acoustic dosimeters were cycled through each of the ISS pressurized modules or areas of concern, such as areas near exercise equipment, fans, etc. to help determine high noise levels which can affect crew noise exposure. These locations are defined in a "static-deploy plan" by the JSC Acoustics Office and provided to the crew before the activity. Measurements have been recorded in various locations in the U.S. and Russian segments. The data logging feature on the dosimeters are a great tool for assessing and evaluating continuous or intermittent sources of noise in the environment by providing time-stamped acoustic data. However, during nominal and/or off nominal noise surveys, the ISS crewmembers have the option to take noise measurements with the sound level meter and/or acoustic dosimeter. If the measured noise level during a crew activity or task exceeds 60 dBA and is not documented in the crew procedures, then it will be included in the NHI and applicable hearing protection requirements will be documented for future crew task or activities.

Figure 14. Acoustic dosimeter used for a static measurement near the IMV fan in the JPM.

As an example of a static measurement, an acoustic dosimeter was used to assess the performance of one of the IMV fans located in the Japanese Pressurized Module (JPM). Debris from ISS tends to clog IMV fans which eventually stalls the fan and increases the sound levels. Once the fan was cleaned, the sound levels return back to nominal. See Figs. 14 and 15. As you can see in the historical plot (Fig. 15), when an IMV fan is stalled it produces sound levels in the mid-60s dBA. Once the fan is cleaned the levels return to nominal levels (mid 50s dBA). However, during this last static measurement conducted on February 2017, after the fan was cleaned the levels did not fully returned to nominal levels. Another possible noise source may have affected the levels in the JPM.

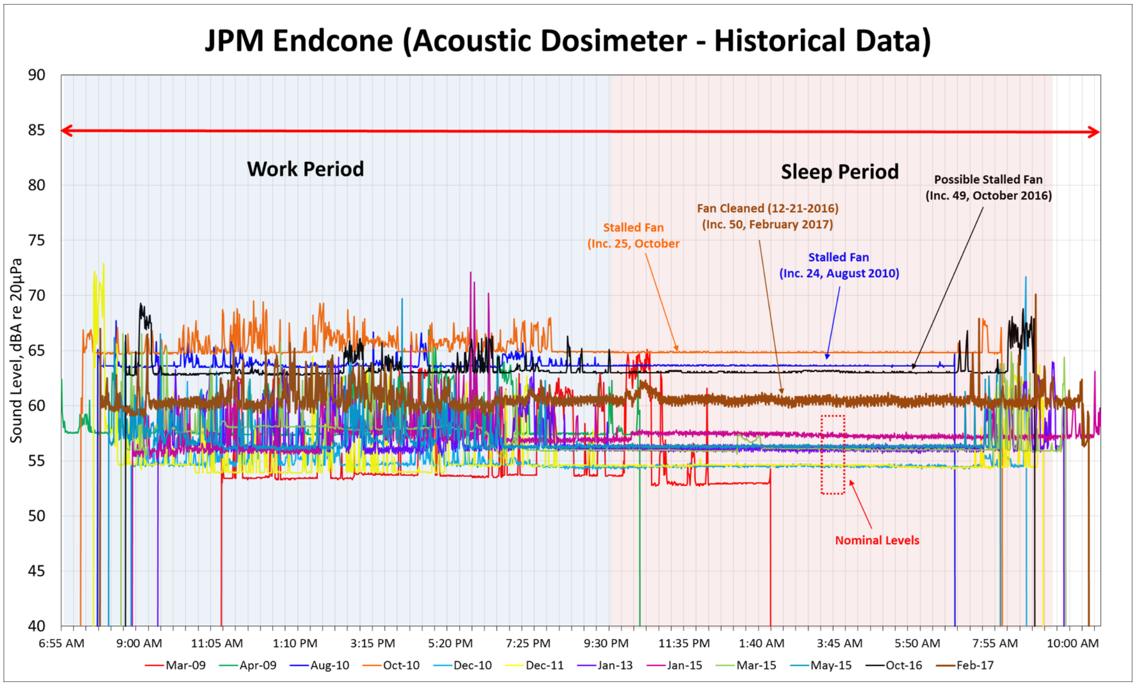

Figure 15. Acoustic Dosimeter Static Measurement – JPM Endcone Location (Next to IMV Fan).
SOURCE: Acoustic dosimeter data collected on January 2017 (Inc. 50).

III. Discussion

This paper describes the ISS noise exposure monitoring program as well as an assessment of acoustic dosimeter data collected since May 2015 (Inc. 43) to date (Inc. 51). Acoustic data has been collected onboard ISS since it was first inhabited by three crewmembers on November 2001 (Increment 1). The data also provided trending information with regards to the work and sleep acoustic environments experienced by the crewmembers on ISS. The average noise exposure level in the ISS work environment during this reporting period (Inc. 43-51) has fluctuated from 68 to 71 dBA. The sleep environment average noise exposure level has also fluctuated from 51 to 57 dBA during this reporting period. Figure 16 provides you with a graphical representation on how the ISS' nominal acoustic environment compares to everyday sounds. Then again, when a crewmember is running on the treadmill at speeds greater than 10 mph, noise levels can be measured above 85 dBA (noise hazard level). Overall, there has been an improvement in the acoustical environment on ISS, with the exception of transient environmental conditions caused by off-nominal hardware performance (e.g. stalled IMV fans). After maintenance was performed, levels returned back to nominal levels. The measurements collected to date were highly dependent on the activities/tasks the crew performed during their stay on ISS, whether occupational or leisure, as well as environmental conditions on ISS. Lessons learned with regards to successful noise control techniques, acoustic requirements and flight rules from past space programs (e.g. Space Shuttle, Apollo, etc.) have shown to be very beneficial in helping reduce the environmental noise levels and at the same time reduce the crew noise exposure level on ISS.

IV. Conclusions

The crewmembers on ISS have several modules in which they can spend time during the day. Accurately tracking their activities, tasks, and noise exposure in these modules is a significant task. The current acoustic dosimeters used onboard ISS have the capability for measuring and logging data. However, correlating crew activities to the measured data can be a difficult task unless a crewmember's timeline is well defined with time stamps corresponding to completed activities.

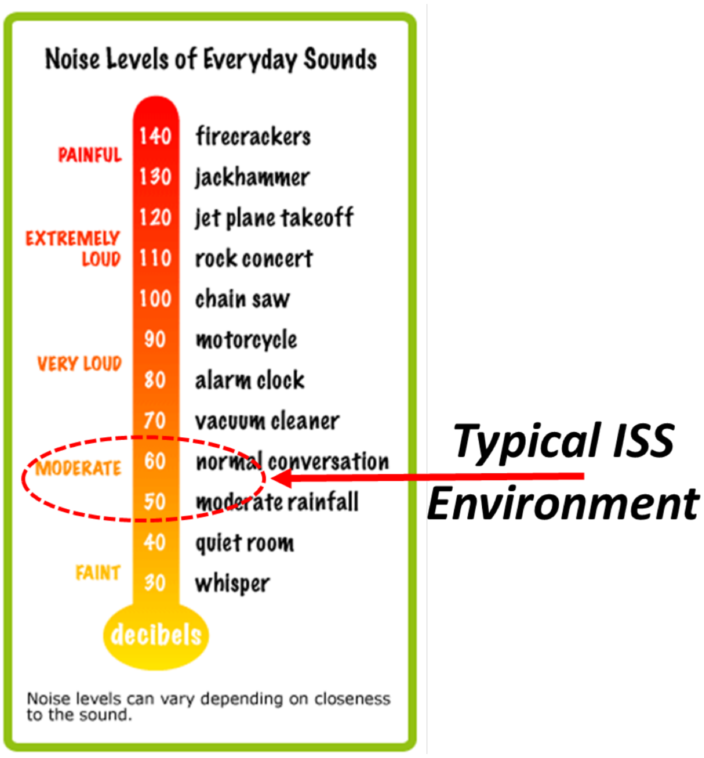

Figure 16. Noise Levels of Everyday Sounds.
SOURCE: NIOSH

As part of the Noise Level Constraint ISS Flight Rule, data were collected during the acoustic dosimetry sessions with the basis for the identification and mapping of high-noise areas and activities on ISS that can contribute significantly to the noise exposure experienced by the ISS crewmember. These data were then documented in the NHI. The NHI was based on the data collected with the acoustic dosimeter, using the 3-dB equal energy ER. The NHI was provided to the crewmembers during every ISS increment since Inc. 36 (July 2013) and updated when any activity or task exceeded the noise hazard level. HPDs were required when the 16-hour L_{EQ} was 72 dBA or greater but only during activities where high noise exposure levels were present. Likewise, HPDs were recommended to the crew when the L_{EQ16} was 60 dBA or greater. Also, HPDs were always required when the L_{EQ} was at or above the noise hazard limit.

During this reporting period, ISS Inc. 43-51 (May 2015 – April 2017), data have shown that levels are dependent on the acoustic environment and the activities and tasks being performed by the crewmember. Static dosimetry has also proven to be an aid for identifying hardware anomalies. As we learn how to better correlate the crew timeline, tasks, activities, and anomalies with the measured acoustic dosimetry data, our ability to protect the crewmembers onboard ISS will be enhanced.

Future acoustics research will aim to relate ISS noise exposures to auditory and non-auditory effects of noise, especially how acoustic conditions can affect hearing sensitivity, human performance, sleep and crew health on the ISS.

Acknowledgments

The authors would like to thank the ISS Biomedical Engineers for helping with the crew procedures, training, anomaly resolutions and serving as the liaison to the ISS crew; the hardware engineers for keeping the acoustic dosimeters certified and ready for flight; and the International Partners for their collaboration with the noise exposure monitoring program.

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