# S&T Project 8141: Hoover Dam Powerplant Noise Control Research – Survey Results Post Controls Install

**Science and Technology Program**
**Research and Development Office**
**Final Report No. ST-2021-PROJECT ID 8141-REPORT NUMBER 01**
**NCE Report #2021-006**

**U.S. Department of the Interior**

July 6, 2021

| REPORT DOCUMENTATION PAGE | | | | | *Form Approved OMB No. 0704-0188* |
|---|---|---|---|---|---|



| 1. REPORT DATE *(DD-MM-YYYY)* | 2. REPORT TYPE | 3. DATES COVERED *(From - To)* |
|---|---|---|
| 06-14-2021 | Research | 2016-2021 |

| 4. TITLE AND SUBTITLE | 5a. CONTRACT NUMBER<br>WBS/WOID |
|---|---|
| **S&T Project 8141: Hoover Dam Powerplant Noise Control Research – Survey Results Post Controls Install** | 5b. GRANT NUMBER<br>IA: R20PG00127 |
| | 5c. PROGRAM ELEMENT NUMBER<br>1541 (S&T) |
| 6. AUTHOR(S)<br>Bureau of Reclamation | 5d. PROJECT NUMBER<br>Final Report ST- Year2021 -Project ID 8141- Report Number 01 |
| | 5e. TASK NUMBER |
| | 5f. WORK UNIT NUMBER |

| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) | 8. PERFORMING ORGANIZATION REPORT NUMBER |
|---|---|
| Safety and Health Office<br>500 Date St.<br>Building 1400, LC-1008<br>Boulder City, NV 89005 | 2021-006 |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) | 10. SPONSOR/MONITOR'S ACRONYM(S)<br>Reclamation |
| Science and Technology Program<br>Research and Development Office<br>Bureau of Reclamation<br>U.S. Department of the Interior<br>Denver Federal Center<br>PO Box 25007, Denver, CO 80225-0007 | 11. SPONSOR/MONITOR'S REPORT NUMBER(S)<br>Final Report ST- 2021-Project ID 8141- Report Number 01 |

12. DISTRIBUTION/AVAILABILITY STATEMENT
Final Report may be downloaded from https://www.usbr.gov/research/projects/index.html

13. SUPPLEMENTARY NOTES

14. ABSTRACT
A noise survey performed on the Arizona side the Hoover Dam powerplant in Boulder City, NV, in July of 2016 to identify areas of high noise levels. Engineering controls were recommended to reduce noise levels. A prioritized subset of controls was installed on both Arizona and the Nevada sides.

15. SUBJECT TERMS
Noise, Hoover, Hearing

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON<br>Lisa M Duncan, CIH |
|---|---|---|---|---|---|
| a. REPORT<br>U | b. ABSTRACT<br>U | THIS PAGE<br>U | | | 19b. TELEPHONE NUMBER *(Include area code)*<br>702-293-8084 |

**Standard Form 298** (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

# Mission Statements

The Department of the Interior (DOI) conserves and manages the Nation's natural resources and cultural heritage for the benefit and enjoyment of the American people, provides scientific and other information about natural resources and natural hazards to address societal challenges and create opportunities for the American people, and honors the Nation's trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities to help them prosper.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

# Disclaimer

Information in this report may not be used for advertising or promotional purposes. The data and findings should not be construed as an endorsement of any product or firm by the Bureau of Reclamation, Department of Interior, or Federal Government. The products evaluated in the report were evaluated for purposes specific to the Bureau of Reclamation mission. Reclamation gives no warranties or guarantees, expressed or implied, for the products evaluated in this report, including merchantability or fitness for a particular purpose.

# Acknowledgements

The Science and Technology Program, Bureau of Reclamation, sponsored this research through the Office of Naval Research and Interagency agreements. Acknowledgment goes to Michael Green, Safety Engineer in the Denver, CO office who provided substantial technical and coordination assistance on this project, and John Stemmer in Facilities Maintenance at Hoover Dam, for the installation of the noise controls.

# S&T Project 8141: Hoover Dam Powerplant Noise Control Research – Survey Results Post Controls Install

## Final Report No. ST-2021 PROJECT-ID 8141-REPORT NUMBER 01

**NCE Report 2021-006**

*prepared by* Bureau of Reclamation
Safety and Health Office, Lower Colorado Basin
Lisa Duncan, CIH, CSP, Regional Industrial Hygienist

Additional Authors
Jeffrey Komrower, Noise Control Engineering, Inc.
85 Rangeway Road
Building 2 – 2nd Floor
Billerica, MA 01862
978-670-5339
jeffk@noise-control.com (email)
NCE Job Number: 15527.01

# Peer Review

## Bureau of Reclamation
## Research and Development Office
## Science and Technology Program

Final Report ST-2021-Project ID 8141- Report Number 01

**S&T Project 8141: Hoover Dam Powerplant Noise Control Research – Survey Results Post Controls Install**

LISA DUNCAN Digitally signed by LISA DUNCAN
Date: 2021.07.27 13:35:21 -07'00'

**Prepared by: Lisa M Duncan, CIH, CSP**
**Regional Industrial Hygienist, Safety & Health Office, Lower Colorado Basin**

TAUSEEF BADAR Digitally signed by TAUSEEF BADAR
Date: 2021.08.02 06:42:51 -07'00'

**Peer Review by: Tauseef Badar**
**Industrial Hygienist, Safety & Health Office, California Great Basin-10**

*"This information is distributed solely for the purpose of pre-dissemination peer review under applicable information quality guidelines. It has not been formally disseminated by the Bureau of Reclamation. It does not represent and should not be construed to represent Reclamation's determination or policy."*

# Acronyms and Abbreviations

| | |
|---|---|
| Reclamation | Bureau of Reclamation |
| NCE | Noise Control Engineering, Inc. |

# Measurements

| | |
|---|---|
| dB | Decibel |

# Contents

Page

Mission Statements ........ iv
Disclaimer ........ iv
Acknowledgements ........ iv
Peer Review ........ vii
Acronyms and Abbreviations ........ viii
Measurements ........ viii
Executive Summary ........ 1
1. Introduction ........ 2
2. Methods: Summary of Installed Noise Controls ........ 3
3. Methods: Field Measurements ........ 8
3.1. Measurement Techniques ........ 8
3.2. Measured Noise Levels ........ 9
3.2.1. Draft Tube Floor (Level 1) ........ 10
3.2.2. Turbine Gallery Level (Level 2) ........ 12
3.2.3. Cable Gallery (Level 2-1/2) ........ 14
3.2.4. Main Generator Floor (Level 3) and Generator Top (Level 4) ........ 14
3.2.5. Compressors (Level 2 Central Section) ........ 17
4. Results and Recommendations ........ 18
5. Conclusion: Next Steps ........ 21
Appendix A: Table Summary of Installed Controls and Noise Level Reductions ........ 22

# Executive Summary

When Hoover Dam was built in the 1930s, noise regulations were not yet written, and noise control methods were not yet developed. Due to the number of workers affected by permanent hearing loss from noisy work environments, this study was performed to assess current noise levels, to install controls to reduce noise in areas of the Powerplant most populated by employees and assess the reduction in noise achieved by the installation of controls.

A complete noise survey was performed on the Arizona side of the Hoover Dam powerplant in Boulder City, NV in July of 2016. Based on this survey, a series of engineering controls to reduce noise levels was recommended. The suggested controls were then prioritized, and in a first phase, a subset of the controls was installed on both the Arizona and the Nevada sides of the Powerplant.

A post-installation noise survey was performed in April 2021, and a comparison of noise levels before and after the installation of the controls was made for the Arizona wing, resulting in significant decrease of noise levels. Due to the logarithmic measurements, a significant decrease in noise is anything 3 dB or more.

# 1. Introduction

The primary responsibility of the US Department of Interior Bureau of Reclamation (Reclamation) is to deliver water and generate power. Reclamation oversees a number of hydroelectric powerplants across the U.S. Hearing loss has become the number one workers compensation safety issue in Reclamation. Reducing continuous noise in the powerplants will help prevent hearing loss and will minimize future hearing loss claims as well as create a better working environment.

Over the last 10 years, Reclamation has paid approximately $5.24 million dollars in hearing loss claims. Noise Control Engineering, LLC (NCE) has been working with the Office of Naval Research (ONR) to reduce Noise Induced Hearing Loss (NIHL) issues in military applications. ONR and Reclamation have an Interagency Agreement in place to identify noise sources and help implement engineered noise controls to reduce employee high noise exposure.

A noise survey was performed at the Hoover Dam powerplant in Boulder City, NV in July of 2016. The survey was performed only for the Arizona side of the facility, but based on the noise levels measured, assuming basic symmetry of the plants, a noise control plan was developed for both plants.

The first phase of the plan implementation was accomplished with the installation of noise controls in prioritized areas of both the Nevada and Arizona sides of the Powerplant and a resurvey of both the Arizona and Nevada plants was conducted in April 2021 to assess the level of noise reduction achieved. This report details the results of the noise survey  post-installation of the noise controls.

# 2. Methods: Summary of Installed Noise Controls

A summary of the recommendations for noise control treatments is shown in Table 1. For the initial phase of the plan implementation, those controls highlighted in the table were installed on both the Arizona and Nevada sides.

| Plant Area | | Treatment Proposed |
|---|---|---|
| **Pipe Gallery on Level2 (EL643)** | Eductor Noise from Level 1 Radiating from Floor Grates | Acoustic Silencers |
| | Stairwells from Eductor Level | Absorption Material on Hard Surfaces |
| | Piping from Eductors | Pipe Cladding |
| | Pipe penetrations fromLevel1 | Fiberglass insulation or mineral wool |
| **Turbine Pits (EL643)** | Either side of shaft | High Transmission loss blankets and Frame-Temporary Installation when personnel working operating units |
| **Governor Gallery on Level2 (EL 643)** | Turbine Pit Accesses | Flexible Acoustic Noise Barriers |
| | Generator Underside Accesses | Flexible Acoustic Noise Barriers |
| **Draft Tube Level (EL625)** | Eductor Space Accesses | Flexible Acoustic Noise Barriers(both openings) |
| | Eductor Space | Absorption Material on Hard Surface |
| | Draft Tube Accesses (Eductor Side) | Flexible Acoustic Noise Barriers |
| | Draft Tube Accesses (Butterfly Valve Side) | Flexible Acoustic Noise Barriers |
| **Cable Gallery (EL653)** | Fan Exhaust Vents on Floor | Silencers |
| **Bus Gallery (EL663)** | Flow Noise in Piping | Pipe Cladding |
| **Compressor Area** | Compressor Noise | Install sound absorption material in Compressor 1 just as in units 2&3 |
| | | Better installation of sound panels around Unit 1 and Installation of Sound panels around units 2&3 |

Table 1: Summary of recommended and installed noise controls

[1] “Continued Hydroelectric Powerplant Noise Surveys and Engineering Control Research Final Report: Hoover Dam and Powerplant”, NCE Report No. 2016-019 date September 26, 2016.

Figures 1 and 2 show the flexible strip acoustic curtains that were installed in all the openings between the bays of the Eductor Gallery as well as in the opening from the draft tube corridor on the Eductor Gallery side of Level 1. Figure 3 shows absorption panels that were installed in the draft tube corridors, both the main corridor leading between the Eductor Gallery and the Butterfly Gallery as well as the access corridors leading up the draft tube.

On the level 2 Pipe Gallery, there were a number of open vents that lead directly down to the Eductor Gallery. High noise levels in the Eductor Gallery were contributing to the overall noise levels in the Pipe Gallery through these vents. To reduce this noise, silencers were designed and installed over these vents as shown in Figure 4.

Noise from the Eductor Gallery was also travelling up the staircases to the Level 2 Pipe Gallery. To reduce this noise, absorption panels were installed on the hard surfaces in the stairwells (Figure 5). Figure 6 shows these same absorption panels which were installed in the openings leading from the Turbine Gallery to the Governor Gallery in order to reduce noise entering the Governor Gallery from the Turbine Gallery.

Noise levels in the Cable Galleries between Levels 2 and 3 were very high because of acoustical energy entering the Cable Gallery through vents in the floor leading to the lower levels. Figure 7 shows silencers which were designed and installed over these vents to reduce Cable Gallery noise.


Figure 1. Flexible acoustic strip curtains installed in openings along Eductor Gallery corridor on Level 1

Figure 2. Flexible acoustic strip curtains in openings to eductor bay and draft tube corridor on Level 1

Figure 3. Absorption panels installed on surfaces in draft tube corridors on Level 1

Figure 4. Acoustic silencers over vents from Eductor Gallery to Level 2 Pipe Gallery

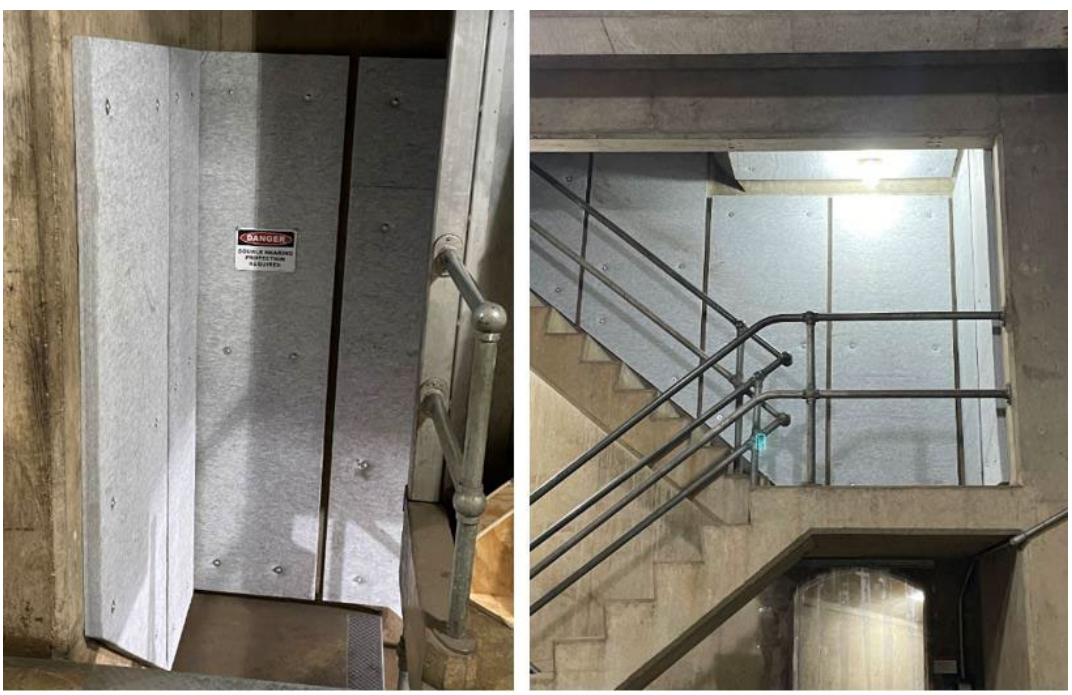


Figure 5. Acoustic absorption panels installed on stairwell from Eductor Gallery to Level 2 Pipe Gallery

Figure 6. Acoustic absorption panels installed in opening from Governor Gallery to Turbine Gallery


Figure 7. Acoustic silencers installed over fan exhaust vents in Cable Gallery

# 3. Methods: Field Measurements

## 3.1. Measurement Techniques

Noise data was acquired using a hand-held walk around spectrum analyzer (Figures 8 and 9). Acoustic measurements were obtained using laboratory quality microphones from PCB. All instrumentation was under calibration from a certified laboratory and in addition, at each facility, end-to-end calibrations were performed to verify sensitivity values of the measurement transducers through the complete measurement chain. The field measurements included storage of raw time data as well as narrowband and one-third octave band (TOB) analysis at multiple locations in each powerplant.

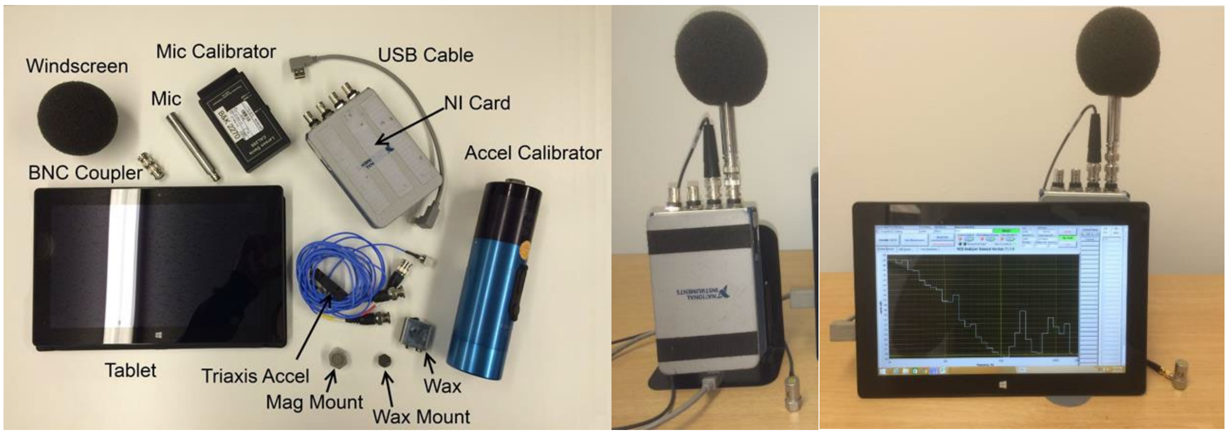

Figure 8. National Instruments/LabVIEW walk around data acquisition system

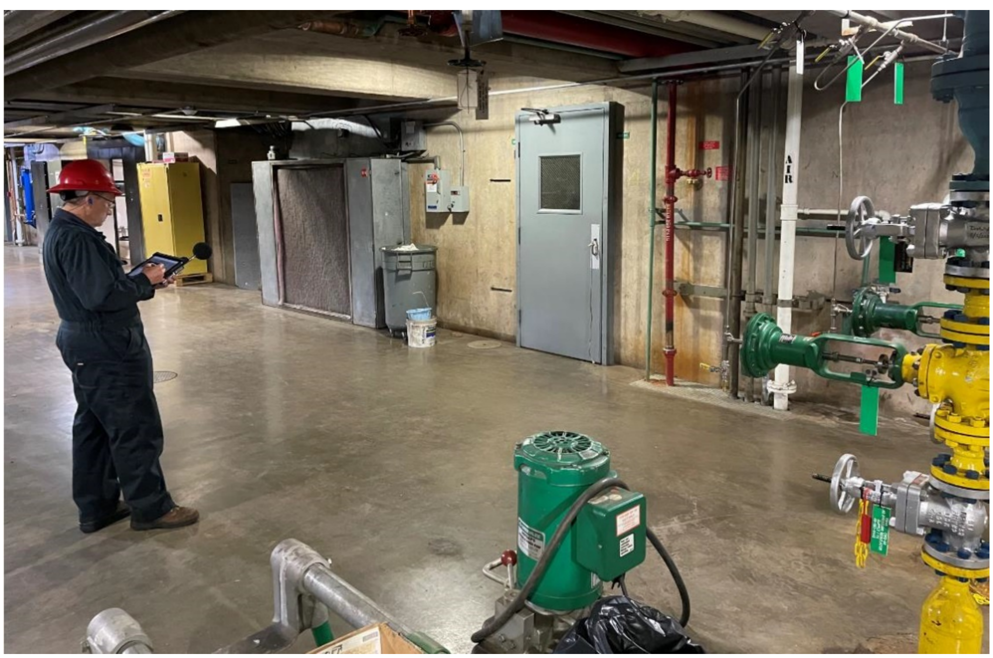
Figure 9. Typical walk around measurement using hand-held system

## 3.2. Measured Noise Levels

NCE performed noise surveys on the Arizona and Nevada sides of the Hoover Dam Powerplant in Boulder City, NV on June 26th and 27th, 2021 after the installation of noise controls in both plants. Measurements were taken for two basic generator operating configurations. Table 2 shows the operating conditions for this survey and also shows the comparable operating loading conditions from the July 2016 test. Generator loading conditions were observed to vary slightly during the test periods while adjusting to load demands, so the loads shown in Table 2 are not specifically accurate, however the overall generator state (loaded, condense off) are accurate. The noise levels remained steady with minor variations in generator load. In condense mode, the generators are spinning, but are not under load.

**Arizona Powerhouse - Low Load Condition**

| Unit | Jul-16 | Apr-21 |
|---|---|---|
| A1 | 77 MW | 84 MW |
| A2 | Condense | Condense |
| A3 | Condense | Off |
| A4 | Condense | Off |
| A5 | Condense | Off |
| A6 | 92 MW | 83 MW |
| A7 | Condense | Off |
| A8 | 39 MW | 35 MW |
| A9 | Condense | Off |

**Arizona Powerhouse - High Load Condition**

| Unit | Jul-16 | Apr-21 |
|---|---|---|
| A1 | 82 MW | 97 MW |
| A2 | Condense | 100 MW |
| A3 | 80 MW | Off |
| A4 | 79 MW | Off |
| A5 | 87 MW | 90 MW |
| A6 | 92 MW | 95 MW |
| A7 | 92 MW | 94 MW |
| A8 | 39 MW | 44 MW |
| A9 | 42 MW | 41 MW |

**Nevada Powerhouse (no survey performed in 2016)**

| Unit | Low Load Condition | High Load Condition |
|---|---|---|
| N1 | 97 MW | 83-101 |
| N2 | Condense | 83-101 |
| N3 | Off | 83-101 |
| N4 | Off | 83-101 |
| N5 | 90 | 83-101 |
| N6 | Condense | 83-101 |
| N7 | Off | Off |
| N8 | 85 | 83-101 |

Table 2: Generator operating conditions for noise surveys at the Hoover Dam powerplant

### 3.2.1. Draft Tube Floor (Level 1)

Figures 10 shows the measured noise levels on the draft tube level for the Arizona Powerhouse in the low-power test condition. For the units that were operating, the loads were comparable. The difference is in the units which were not loaded. In the July 2016 test, all units which were not under load were in condense mode, which means they were spinning, and the eductors were operating. In the April 2021 test, those units, except for unit 2 which not under load were off and not spinning. For the eductor bays, noise levels for the July 2016 test were very high in every bay because the eductors were all operating, ranging from 99-102 dB(A). Noise levels in these same bays during the April 2021 test, where the unit was either operating or in condense mode except for unit 1, were still very high. This is to be expected since there was no treatment applied to the space. It is unclear why the noise level in the unit 1 eductor bay dropped. Noise levels in the bays adjacent to the eductors did see a drop in noise levels which was anywhere from 3-6 dB higher than before treatment.

Inside the draft tube corridors, noise levels were lower by anywhere from 4 to 17 dB, but again, since the units were actually spinning in the July 2016 test, the drops for this condition were most likely not due only to the treatments. For the two comparable locations, in the corridor on the opposite side of unit 1 (from unit 2), and between units 1 and 2, there was a drop of 6-7 dB. Similarly, for the Butterfly Gallery side, drops in noise levels from 2-4 dB were seen outside units 2 and 6 where the conditions were comparable. Noise levels in the other areas on this side were lower in most other locations, but again, most likely due to the non-loaded units being off as opposed to being in condense mode.

Figure 11 shows the measured noise levels on the draft tube level for the Arizona Powerhouse in the high-power test condition. For units A1 and A5 through A9, conditions for both tests were virtually the same. Because of the conditions during the July 2016 test, there were only a limited number of points taken on this level at the high-power condition. For the points in the draft tube corridors where comparable conditions existed, noise levels after treatment were reduced by 4-7 dB. On the Eductor Gallery side, there were no comparable measurements for the bays adjacent the eductor bays. Noise levels in these areas were all still above 85 dB(A) during the April 2021 test near operating units, ranging from 88 to 92 dB(A). In the Governor Gallery, comparable noise levels were reduced by 2 dB, but again, near operating units, noise levels were still above 85 dB(A) ranging from 85 to 89 dB(A).

Figures 12 and 13 show the measured noise levels for the Nevada plant draft tube levels for the low power and high-load conditions during the April 2021 tests after the installation of noise controls. Data was not acquired in the Nevada during the July 2016 testing. As can be seen, for the low-power operating condition, noise levels in the Eductor bays where the units were operating, or condensing (eductors operating) were consistent with the levels on the Arizona side and ranged from 98 to 102 dB(A). In the bays directly adjacent to the operating eductor bays, noise levels ranged from 87-93 dB(A). Noise levels in the rest of the bays, except for one location near unit 7, were all above 85 dB(A). In the Governor Gallery, for this operating condition, noise levels were all at or below the 85 dB(A) targets with the highest levels near operating unit 1 at 85 dB(A). For the high-power operating condition where all units were operating (except for unit 7), as expected, noise levels in the draft tube corridors between two operating units increased significantly, now ranging from 84-94 dB(A). Eductor Gallery noise levels were very similar to the low power condition with all bays being above the 85 dB(A) targets except for the very end bays by units 1 and 8. Governor Gallery noise levels increased slightly with many locations still at or below the 85 dB(A) targets but now a number of locations near operating units were in the 86-87 dB(A) range.

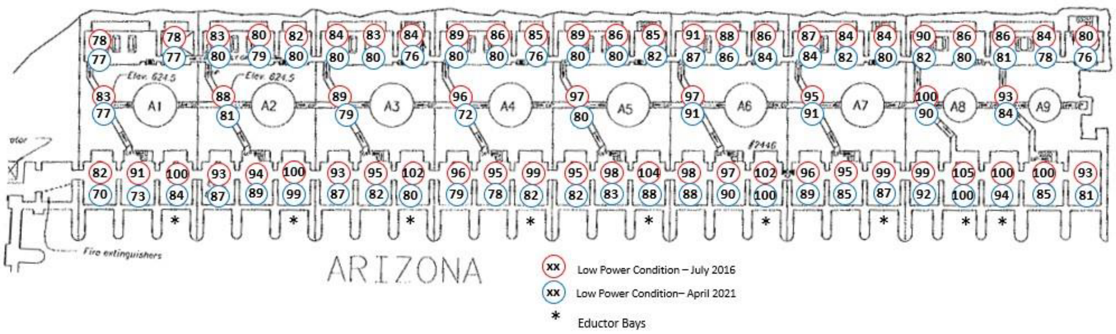


Figure 10: Arizona Plant noise levels (dBA) on Draft Tube Level (Level 1) for low power condition

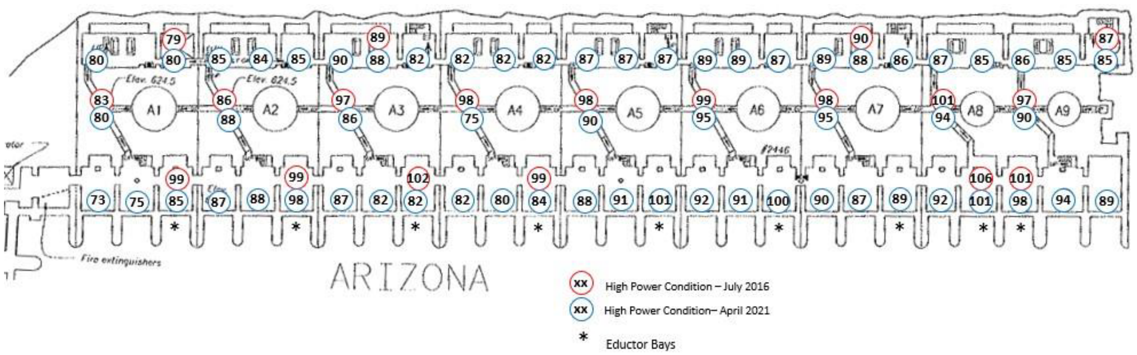


Figure 11: Arizona Plant noise levels (dBA) on Draft Tube Level (Level 1) for high power condition

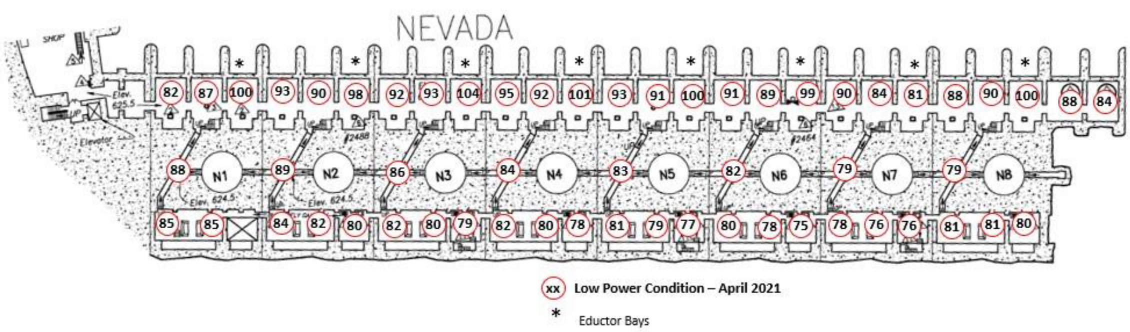


Figure 12: Nevada Plant noise levels (dBA) on Draft Tube Level (Level 1) for low power condition

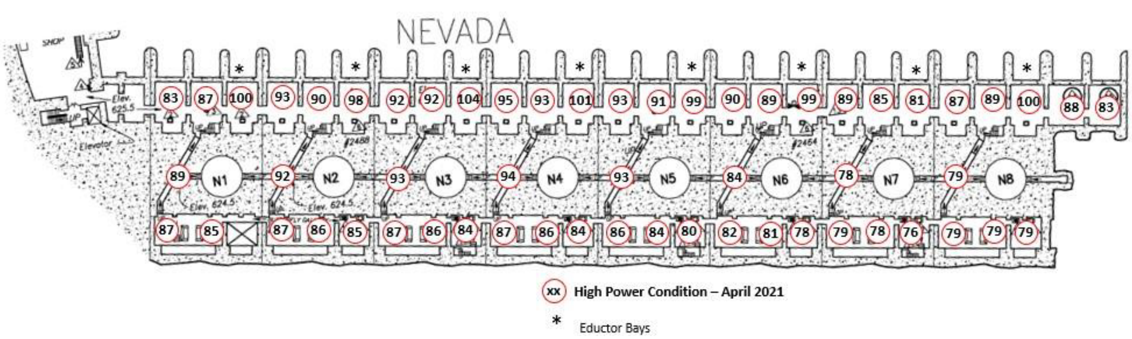


Figure 13: Nevada Plant noise levels (dBA) on Draft Tube Level (Level 1) for high power condition

### 3.2.2. Turbine Gallery Level (Level 2)

Figures 14 and 15 show measured noise levels on the Turbine Gallery level (Level 2) for the low power and high-power conditions in the Arizona plant. Absorption panels were installed in the arches of the openings between the Turbine Gallery and the Governor Gallery. In the Pipe Gallery, silencers were installed over the vents on the floor that were open directly to the Eductor Gallery below. Absorption panels were also installed on the walls of the stairwells leading down to the Eductor Gallery. In the Governor Gallery, noise levels were very comparable between the July 2016 and the April 2021 tests for the low-power condition. Near the operating units where noise levels inside the Turbine Gallery were similar between both tests, noise levels in the Governor Gallery were also similar. In other areas inside the Turbine Gallery, such as near units 2 through 5 which were off, turbine pit noise levels were 3-7 dB lower in April 2021 compared to July 2016, and the Governor

Gallery noise levels outside those units were also comparably lower. In the Pipe Gallery, noise level reductions in several areas were as high as 6-10 dB. This area is not really affected by turbine pit noise because of the doors to the turbine pit but is more influenced by noise from the Eductor Gallery below as well as the Fisher valves and generator cooling units. Throughout the Pipe Gallery noise levels were lower at all locations with reductions ranging from 1 to 10 dB. For the locations near the units which were operating in both tests (units 1,6 and 8), noise levels were 2-8 dB lower after controls were installed. Except for the very end of the Gallery near unit 9, where levels of 90 & 93 were observed, the highest levels throughout the rest of the Gallery after controls installation was 88 dB(A). Before the controls were installed, the highest level was 95 dB(A) and the majority of the measurements ranged from 90-95 dB(A).

For the high load condition, except in the vicinity of units 3 & 4 which were off in the April 2021 test, noise levels inside the turbine pit were comparable between the tests. Again, due to limited availability of this condition in July 2016, only a few points on this level at this condition were measured prior to controls installation. In the Governor Gallery, between units 7 and 8, a 3 dB reduction was observed after controls installation. A 7 dB reduction was seen between units 3 and 4, but this is believed to be due to units 3 & 4 not operating in the April 2021 test. Overall, noise levels in the Governor Gallery were 85 dB(A) or below except between units 5 through 7 where the levels ranged from 86-88 dB(A). In the Pipe Gallery, measurements in the July 2016 test were all taken around operating units and for these locations, reductions of 3-6 dB were observed after controls were installed. Noise levels throughout the Pipe Gallery ranged from 83 to 90 dB(A) where before the installation, levels as high as 95 dB(A) were measured.

Figures 16 and 17 show the noise level measurements taken on the Turbine Gallery level for the Nevada plant for low-load and high-load conditions. Again, no measurements were taken on the Nevada side during the pre-controls July 2016 test. Noise levels in the Turbine Gallery ranged from 83 to 89 dB(A) for the low-load condition. In general, noise levels in the Turbine Gallery were comparable to the Arizona side with expected variations due to slightly different operating conditions (units in condense mode vs off). In general, around Unit 1, which was operating for tests in both plants, levels were slightly higher on the Nevada side, but probably due to Unit 2 operating in condense mode in the Nevada plant and being off in the Arizona plant. Near Unit 5 which was in operation on the Nevada side, noise levels on either side were 85 dB(A) whereas on the Arizona side, noise levels near operating Unit 6 ranged from 89-90 dB(A). Pipe Gallery noise levels were lower in the Nevada plant with all measurements for this condition being below the 85 dB(A) targets, ranging from 78 to 84 dB(A).

For the high-load For the high-load condition, Turbine Gallery noise levels were very comparable to the Arizona wing. Around operating units, noise levels were 91-94 dB(A). In the Governor Gallery, noise levels for this condition again were comparable to the Arizona side. Noise levels outside the openings for operating units ranged from 85-90 dB(A) with the only levels below 85 dB(A) near unit 7 which was not operating. In the Pipe Gallery, noise levels seemed slightly lower than in the Arizona wing, ranging from 84 to 88 dB(A) except near non-operating unit 7, where levels ranged from 82-83 dB(A).

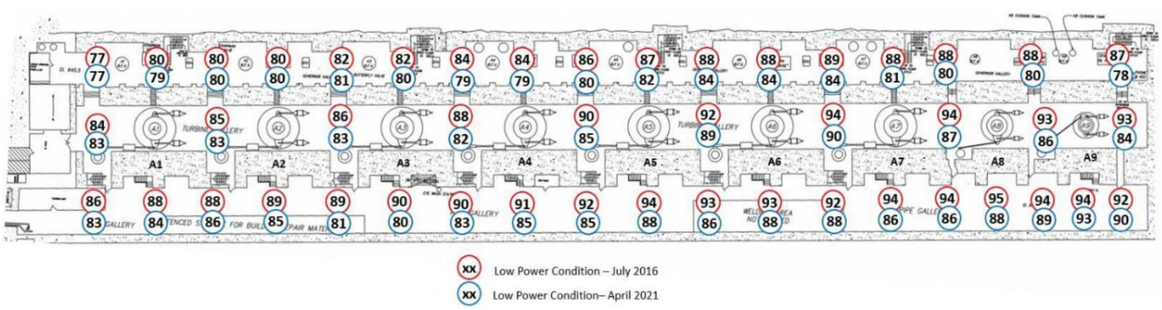

Figure 14: Arizona Plant noise levels (dBA) on Turbine Pit Level (Level 2) for low power condition

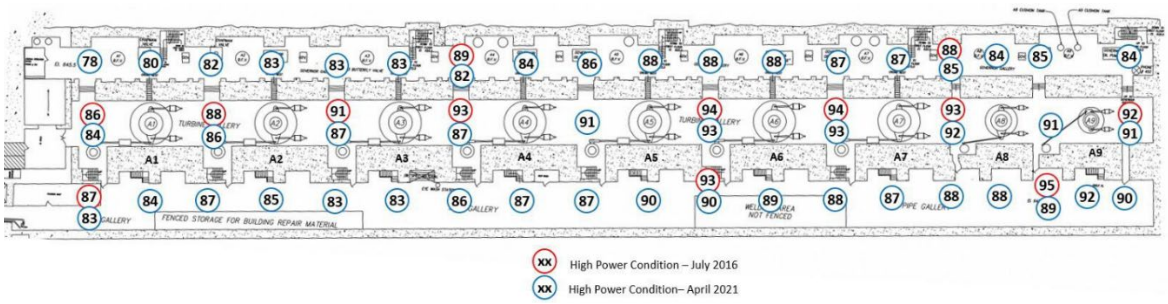

Figure 15: Arizona Plant noise levels (dBA) on Turbine Pit Level (Level 2) for High power condition

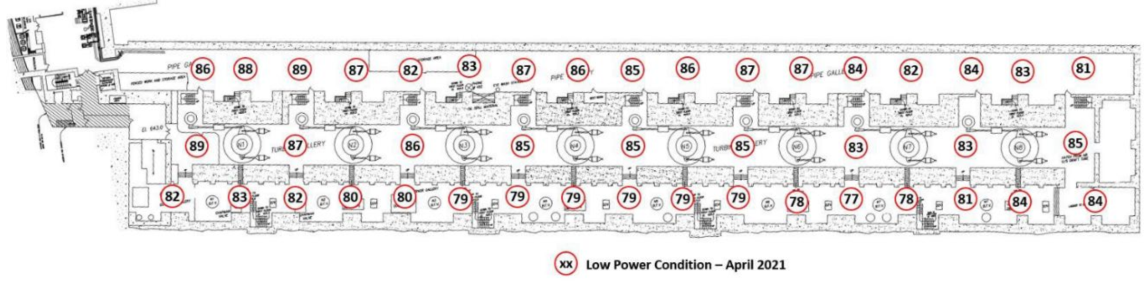

Figure 16: Nevada Plant noise levels (dBA) on Turbine Pit Level (Level 2) for low power condition

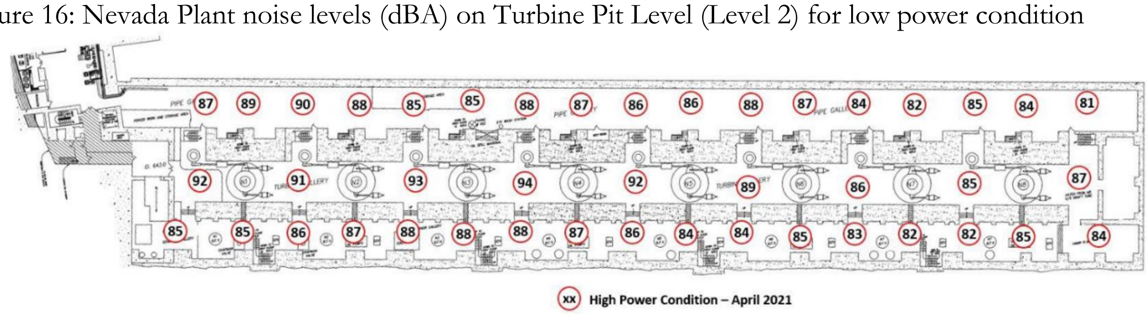

Figure 17: Nevada Plant noise levels (dBA) on Turbine Pit Level (Level 2) for high power condition

### 3.2.3. Cable Gallery (Level 2-1/2)

Figures 18 and 19 show the measured noise levels in the Cable Gallery for both plants. On the Arizona side, before installation of noise controls, noise levels for the low power condition ranged from 87-94 dB(A). After the silencers were installed over the floor vents, noise levels dropped 4 to 11 dB, now ranging from 77 to 83 dB(A) with only one location near unit 7 reaching 86 dB(A). For the high-power condition, noise levels were only slightly higher with all locations at or below the 85 dB(A) criteria except for an 87 dB(A) reading near unit 7. On the Nevada side, all locations for the low-power condition were below the 85 dB(A) targets. For the high-power condition, most locations were below the 85 dB(A) target with only 2 locations near units 1 and 2 above the target ranging from 86-87 dB(A).

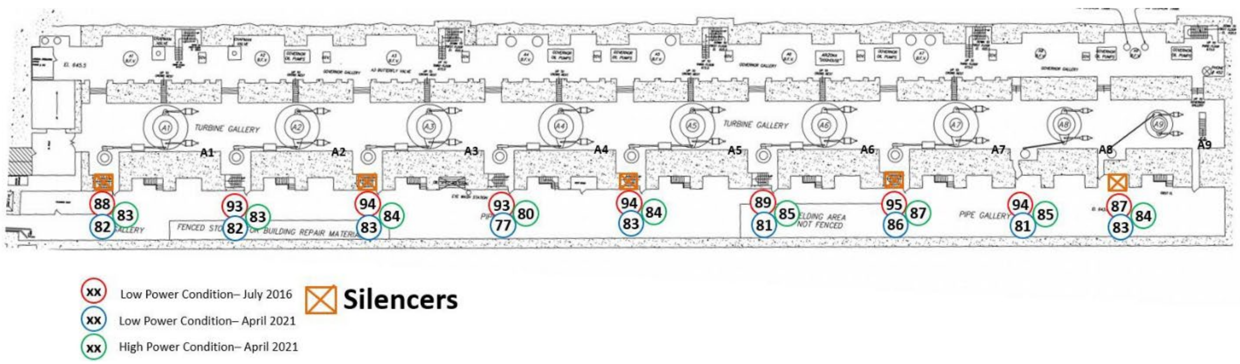


Figure 18: Arizona Plant noise levels (dBA) in Cable Gallery (Level 2-1/2)

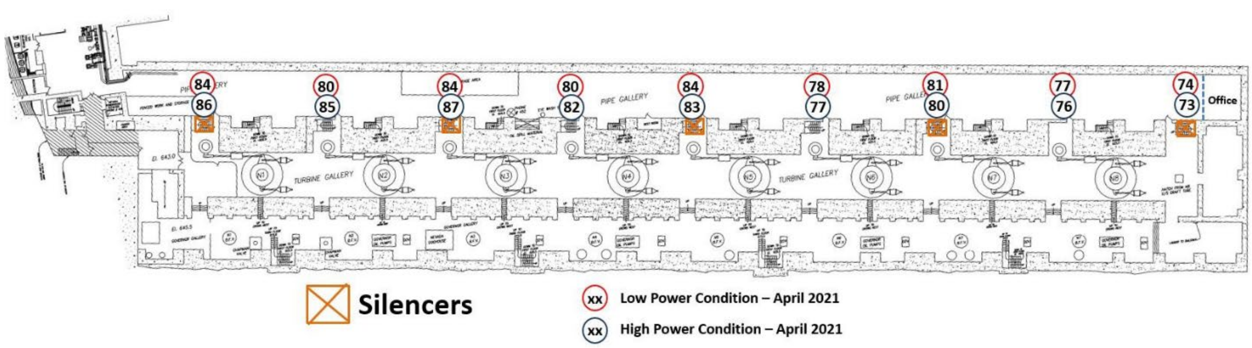


Figure 19: Nevada Plant noise levels (dBA) in Cable Gallery (Level 2-1/2)

3.2.4 Main

### 3.2.4. Main Generator Floor (Level 3) and Generator Top (Level 4)

Figures 20 through 23 show the noise levels on the main generator floor (Level 3) for both plants at the low-power and high-power load conditions. There were no controls installed on this floor. All noise levels are below the 85 dB(A) targets for both conditions and the noise levels are comparable between the July 2016 and the April 2021 tests with the slight differences most likely due to the difference in operating conditions with several generators in condense mode in 2016 vs off in 2021. There were a few locations in the CO2 Gallery that were above the 85 dB(A) target, but those locations were very close to the generator housing and personnel do not spend any time right at those locations.

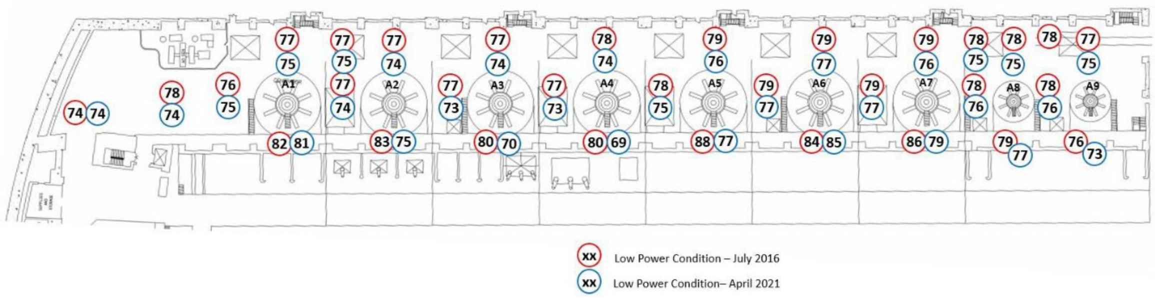


Figure 20: Arizona Plant noise levels (dBA) on Main Generator Floor and CO2 Gallery (Level 3) for low power condition

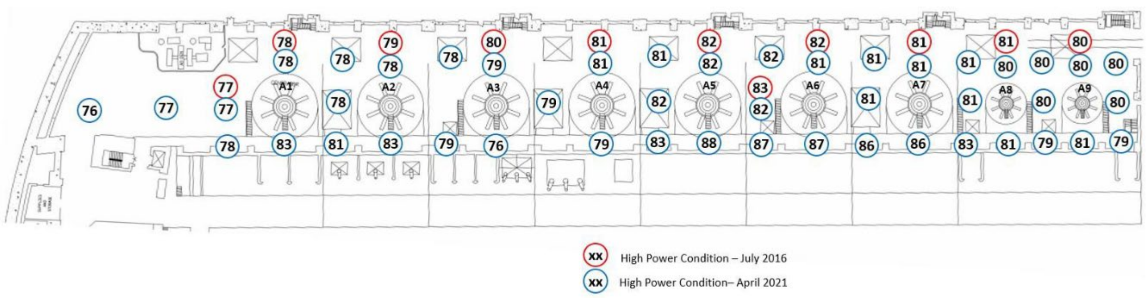


Figure 21: Arizona Plant noise levels (dBA) on Main Generator Floor and CO2 Gallery (Level 3) for high power condition

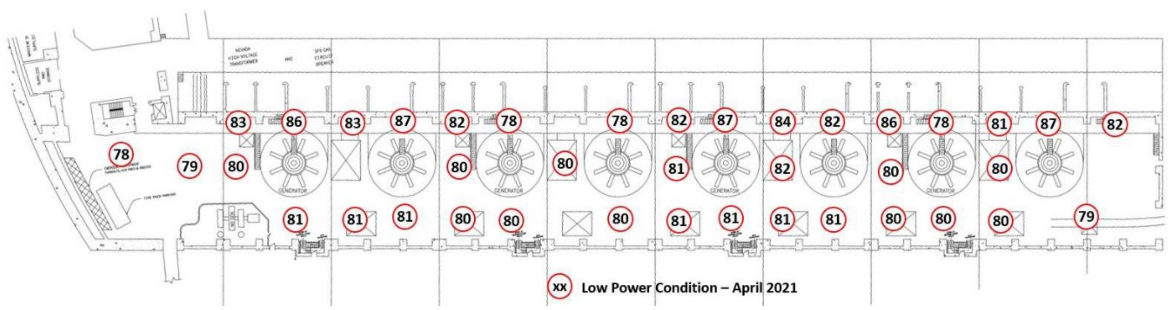


Figure 22: Nevada Plant noise levels (dBA) on Main Generator Floor and CO2 Gallery (Level 3) for low power condition

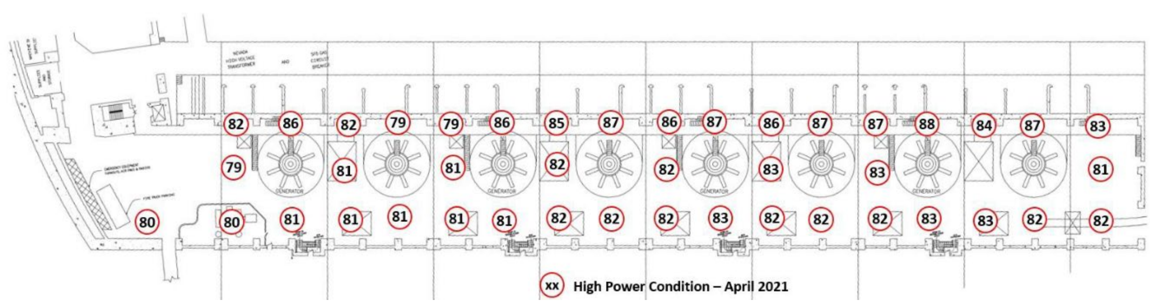


Figure 23: Nevada Plant noise levels (dBA) on Main Generator Floor and CO2 Gallery (Level 3) for high power condition

Figures 24 through 27 show the measured noise levels at the generator top elevation (Level 4) for both the Arizona and Nevada plants for the low-power and high-power loading conditions. As can be seen, all noise levels for these locations are below the 85 dB(A) for both conditions. The measured noise levels on the Arizona side are again comparable between the 2016 and 2021 tests with the differences most likely attributed to generators in 2016 being in condense mode as opposed to being off in the 2021 test.

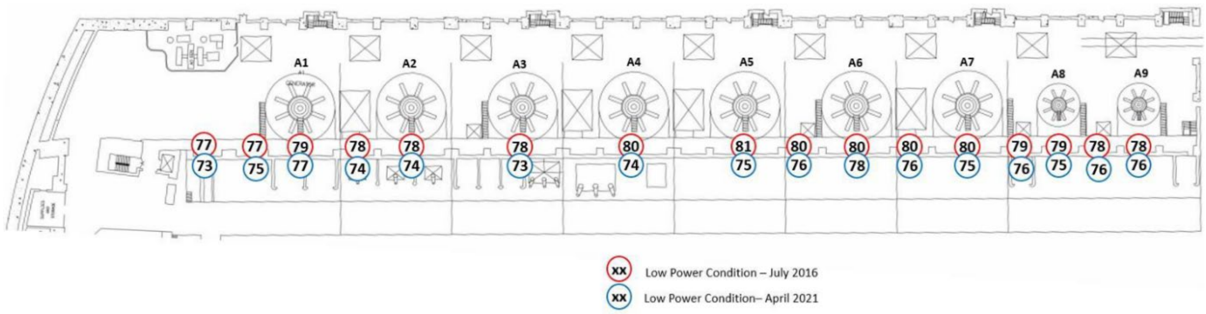


Figure 24: Arizona Plant noise levels (dBA) on Generator Top Level (Level 4) for low power condition

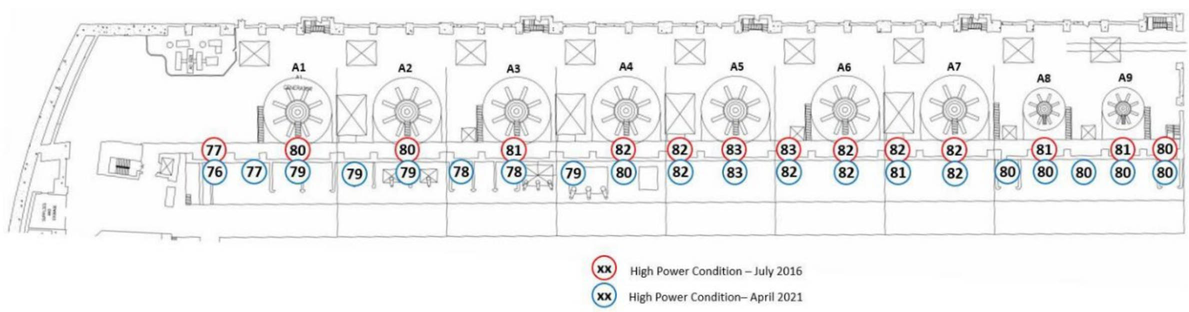


Figure 25: Arizona Plant noise levels (dBA) on Generator Top Level (Level 4) for high power condition

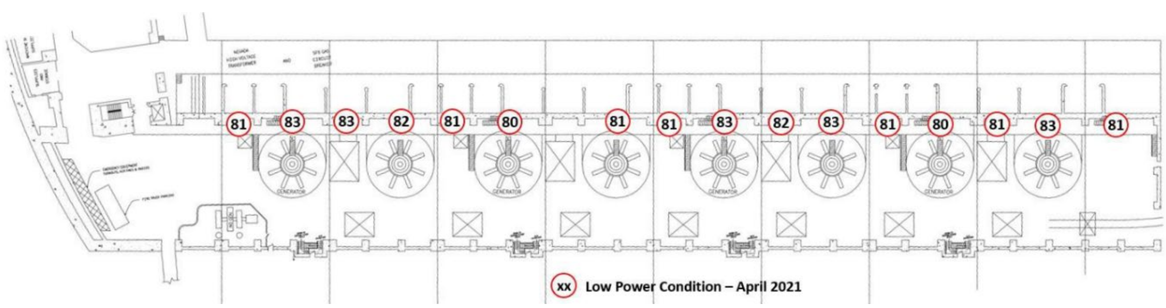


Figure 26: Nevada Plant noise levels (dBA) on Generator Top Level (Level 4) for low power condition

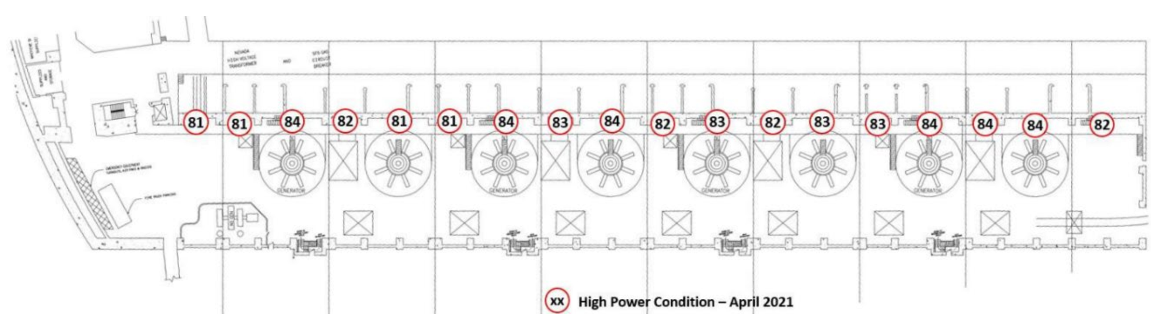


Figure 27: Nevada Plant noise levels (dBA) on Generator Top Level (Level 4) for high power condition

## 3.2.5. Compressors (Level 2 Central Section)

Noise measurements were taken around the compressors on Level 2 in the central plant area between the Arizona and Nevada plants in July of 2016. With only one compressor operating, noise levels ranged from 84 dB(A) to as high as 91 dB(A). As can be seen in Figure 28, there were very little noise attenuation around the compressors. The compressor housings did have some insulation and Compressor 1 did have some clear acoustical strip curtains around it, but the curtains were not sufficiently heavy to block any significant sound and they were not sealed around the compressors which allowed most of the acoustical energy into the plant area. Acoustic blankets were installed around the units, as can be seen in Figures 28 and 29.

Unfortunately, when measurements were being acquired during the April 2021 test, work was being performed on Compressor 3 and gaps in the blankets were present. Figure 30 shows measurements acquired during both tests. As can be seen, noise levels near the side of Compressor 2, which was the only one operating during the April 2021 test, were similar to the July 2016 measurements because the acoustic blankets were not closed. On the back side of the compressors, where the blankets were sealed, the noise level, even right next to the operating compressor was 80 dB(A) compared to a comparable measurement of 84 and 86 dB(A) next to compressor 1 during the July 2016 test. On the end of Compressor 3, after the blankets were installed, the noise level measured was 76 dB(A) compared to 85 dB(A) during the July 2016 test, even though the operating compressor (No. 2) was closer to this point than the July 2016 test when Compressor 1 was operating.


Figure 28: Before and after pictures around compressors (Level 2) showing controls

Figure 29: Acoustic blankets installed around compressors

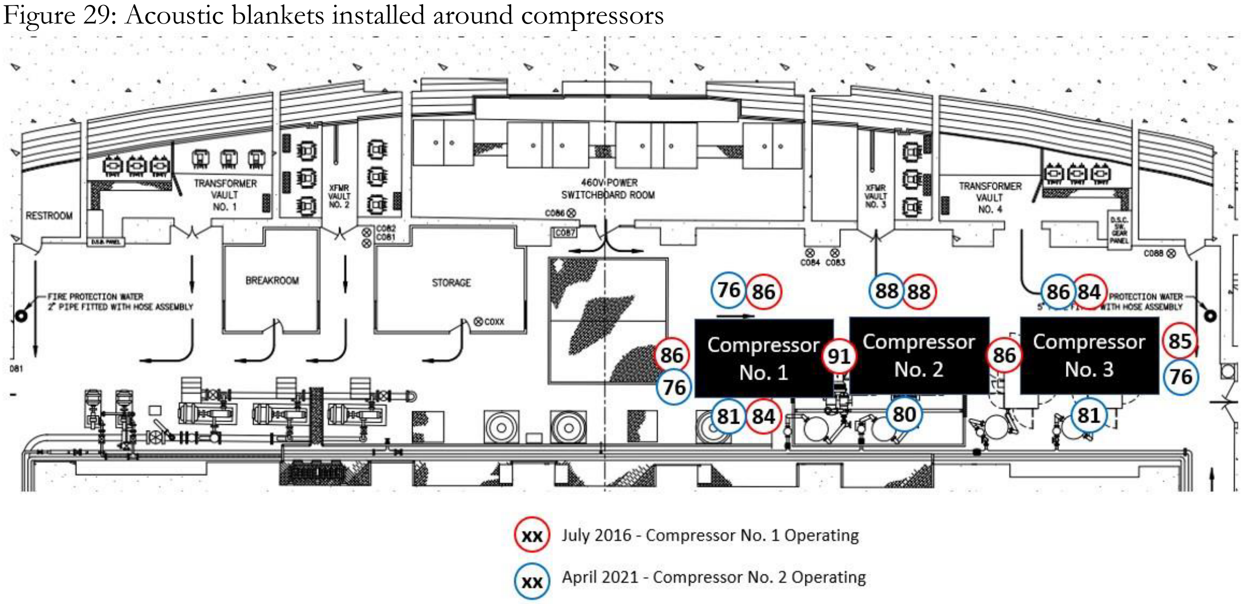


Figure 30: Noise levels (dBA) in central area around compressors (Level 2)

# 4. Results and Recommendations

Noise levels in the main plant areas on Levels 3 and 4 were still below 85 dBA in both power houses except for a couple of locations in the CO2 gallery in the near field of the generators. The noise in these spaces is primarily from the generator housing and access doors but it is also a highly reverberant space, which adds to the high levels. Overall, levels in the space could be reduced by adding absorption on the hard wall surfaces, but it is unlikely that the levels right next to the generator accesses would be significantly reduced because the location is in the near field of the source. Plant personnel also do not spend much time in this area, so no further action at this time is recommended except if personnel will be near these areas, hearing protection should be worn.

Prior to installation of engineering controls, the majority of locations in the Arizona plant Cable Gallery had noise levels above 95 dB(A) reaching as high as 100 dB(A). The main sources were noise from the lower-level Turbine Gallery entering the space through vents on the floor as well as some noise from generator cooling system air flow. Although not a high traffic area, these high noise levels on the Nevada side were very disturbing to workers who constantly travelled this area to reach the  Builder Repairs office which is located near unit 8 on this level. Silencers were installed over the vents which lowered the noise levels in the Arizona plant by 4-11 dB with the majority of the Cable Gallery in both plants now below the target level of 85 dB(A). The only high noise levels that remain are due to air flow from generator cooling system which is very localized near the vents that open into the space. If personnel were to be near this location, hearing protection would be needed, but no additional engineering controls are recommended.

No treatments were installed inside the Turbine Galleries, so noise levels remained consistently above the 85 dBA targets ranging from 86 to 94 dBA in both wings. In order to significantly reduce noise levels, it would be necessary to treat as much as 50% of the hard wall surfaces with absorption material. However, it is assumed that the main reason why personnel would be in the space would be to work on a unit that was not operating. In this instance, it is suggested that a temporary noise barrier consisting of a frame and high transmission loss blankets be constructed and made available when work is being performed on non-operating units to reduce noise exposures from other operating turbines. This noise barrier should be installed on either side of the unit where the work is being performed and can be constructed such that workers would be protected while in that space and then easily removed when the work is completed.

In the Governor Gallery, noise levels near openings to the Turbine Gallery and the Crow's Nest typically were consistently above the 85 dB(A) target levels and ranged from 85-90 dB(A) near units that were operating. Some absorption material was installed in the archway of the opening leading to the Turbine Gallery, but the surface area coverage was not sufficient to significantly lower the noise levels in the Governor Gallery. If it is desired to reduce noise levels further in the Governor Gallery, which will depend on the amount of time workers spend in that area, the most effective way would be to install either acoustic strip curtains or acoustic blankets in the openings both to the Turbine Pit and Crow's Nests. If all openings were treated, noise levels should be reduced below the targets throughout the Governor Gallery.

The silencers which were installed on the floor vents and the absorption panels installed in the stairwells leading to Level 1 significantly reduced noise levels in the Pipe Gallery by treating the highest sources. However, noise levels at many locations near operating units are still above the 85 dB(A) targets reaching as high as 88 dB(A) in the Nevada Wing and as high as 92 dB(A) near Unit A9 in the Arizona Wing. The sources of these continued high noise levels are the Fisher Valves and air flow from cooling air exhausts (Figure 31). It is believed that of these two sources, the Fisher Valves are the highest contributor to current noise levels and additional engineering controls should be explored. Possible controls which could eliminate at the source could include noise attenuators such as Fisher Whisper trim cage, vent diffusers, and noise attenuation trim. In addition to these primary options, these valves and associated piping could be wrapped with cladding material which is of the same construction as the acoustic blankets used to enclose the compressors. If additional reduction in noise levels is still needed after this treatment, then control options to reduce noise from the exhaust opening can be explored.

Figure 31: Fisher valves and generator cooling air exhaust

On the draft tube level, lower levels in the draft tube corridors did result in a noise levels reduction of 2-4 dB. However, due to the highly reverberant nature of the space and contribution from Penstock flow, noise levels were still above the 85 dB(A) targets in the areas near operating units. Installing acoustic strip curtains in the draft tube corridor openings will help reduce noise levels further, but effective noise reduction would most likely only be accomplished by installing absorption panels on the hard wall surfaces if the time spent in this area by workers is sufficient to justify costs. If no further controls are installed, hearing protection should be worn whenever entering these areas.

Inside the draft tube corridors, the absorption panels that were installed resulted in a 4-7 dB reduction in noise levels for areas where conditions could be compared between tests. Noise levels were still very high ranging from 90-95 dB(A) near operating units for both wings. Only a relatively small surface area of these corridors was actually treated and, if deemed necessary, noise levels could still be significantly reduced by adding more absorption material. In a highly reverberant space such as this, a coverage of at least 50 percent of the total surface should be the target.

Noise levels in the Eductor Gallery are still very high. As expected, in the bays where the inductors are located, no noise level reduction was achieved because no controls were installed. The acoustic strip curtains which were installed between the bays along the corridor and in the opening to the draft tube corridors did reduce noise levels by 4-7 dB. However, again due to the highly reverberant nature of the space, noise levels in all of the areas adjacent to bays that contained the eductors ranged between 90-95 dB(A) with no area near operating units being below the 85 dB(A) target. Further reduction of noise levels, if justified by the amount of time that personnel spend in these areas, would most effectively be accomplished by the installation of absorption material.

Based on the measurement taken around the compressors in the Level 2 central section, with the acoustic blankets properly closed and sealed, noise levels around the units should be below the 85 dB targets during normal compressor operation, which typically is up to 2 of the 3 units operating.

# 5. Conclusion: Next Steps

Next steps would be to determine what areas still exhibit noise levels over 85 dB and would benefit from additional engineering controls (worker populated areas).The following recommendations are consolidated from previous sections of this report:

- **Draft tube level 1** - Noise levels could still be significantly reduced by adding more absorption material. In a highly reverberant space such as this, a coverage of at least 50 percent of the total surface should be the target.

- **Eductor Bays** - Further noise reduction could be accomplished by installing absorption panels on the hard wall surfaces if the time spent in this area by workers is sufficient to justify costs. If no further controls are installed, hearing protection should be worn when entering any area of the Eductor Gallery.

- **Butterfly Gallery** - Noise can be further reduced by adding absorption material to this space as well as continuing to lower the noise levels in the draft tube corridors by adding additional absorption in those spaces and installing acoustic strip curtains in the draft tube openings to the Butterfly Gallery.

- **Turbine Gallery** - In order to significantly reduce noise levels, it would be necessary to treat as much as 50% of the hard wall surfaces with absorption material.

  Optionally, since the most likely reason for personnel to be in the turbine gallery would be to work on a unit that was not operating, it is suggested that a temporary noise barrier consisting of a frame and high transmission loss blankets be constructed and made available to reduce exposure to that worker when work is being performed on non-operating units. This noise barrier should be installed on either side of the unit where the work is being performed and can be constructed such that workers would be protected while in that space and then easily removed and stored when the work is completed.

  **Governors Gallery** – The need to reduce noise in this area depends on the amount of time workers spend in that area. The most effective recommendation would be to install either acoustic strip curtains or acoustic blankets in the openings both to the Turbine Pit and Crow's Nests. If all openings were treated, noise levels should be reduced below the targets throughout the Governor Gallery.

  **Pipe Gallery** - It is believed that the Fisher Valves are the highest contributor to current noise levels and additional engineering controls should be explored. Possible controls which could eliminate noise at the source could include noise attenuators such as Fisher Whisper trim cage, vent diffusers, and noise attenuation trim.

  In addition, the valves and associated piping can be wrapped with cladding material of the same construction as the acoustic blankets used to enclose the compressors. If additional reduction in noise levels is still needed after this treatment, then control options to reduce noise from the exhaust opening can be explored.

# Appendix A: Table Summary of Installed Controls and Noise Level Reductions

| Plant Area | | Treatment Proposed | Noise Reduction Achieved (dB) | Notes |
|---|---|---|---|---|
| Pipe Gallery on Level 2 (EL 643) | Eductor Noise from Level 1 Radiating from Floor Grates | Acoustic Louvers | 1-10 dB | Silencers very effective. Overall levels reduced average of 6-7 dB. Noise levels still above targets near Fisher Valves and generator cooling units. Additional noise controls needed to reduce levels further |
| | Stairwells from Eductor Level | Absorption Material on Hard Surface | | |
| | Piping from Eductors | Pipe Cladding | | |
| | Pipe penetrations from Level 1 | Fiberglass insulation or mineral wool | | |
| Turbine Pits (EL 643) | Either side of shaft | High Transmission Loss Blankets and Frame - Temporary installation when personnel working on non-operating unit | 0 | No controls installed |
| Governor Gallery on Level 2 (EL 643) | Turbine Pit Accesses | Flexible Acoustic Noise Barriers | 1-2 | Only controls installed were absorption in arched accesses to turbine pits. Need barriers in opening to pits to achieve further reductions |
| | Generator Underside Accesses | Flexible Acoustic Noise Barriers | | |
| Draft Tube Level (EL 625) | Eductor Space Accesses | Flexible Acoustic Noise Barriers (both openings) | 3-6 | Noise reduction achieved in adjacent bays to eductor bays |
| | Eductor Space | Absorption Material on Hard Surface | 0 | No controls installed in actual eductor bays |
| | Draft Tube Corridors | Absorption Material on Hard Surface | 6-7 | Further reductions achievable with more surface coverage |
| | Draft Tube Accesses (Eductor Side) | Flexible Acoustic Noise Barriers | 3-6 | Noise reduction achieved as a result of these barriers and barriers to eductor bays |
| | Draft Tube Accesses (Butterfly Valve Side) | Flexible Acoustic Noise Barriers | 2-4 | These controls were not installed but some reduction seen due to absorption in corridors |
| Cable Gallery (EL 653) | Fan Exhaust Vents on Floor | Silencers | 4-11 | Most locations now below 85 dB(A) |
| Bus Gallery (EL 663) | Flow Noise in Piping | Pipe Cladding | 0 | No controls installed |
| Compressor Area | Compressor Noise | Install sound absorption material in Compressor 1 just as in units 2 & 3 | 6-9 | Noise levels below 85 dB(A) |
| | | Better installation of sound panels around Unit 1 and Installation of Sound panels around units 2&3 | | |