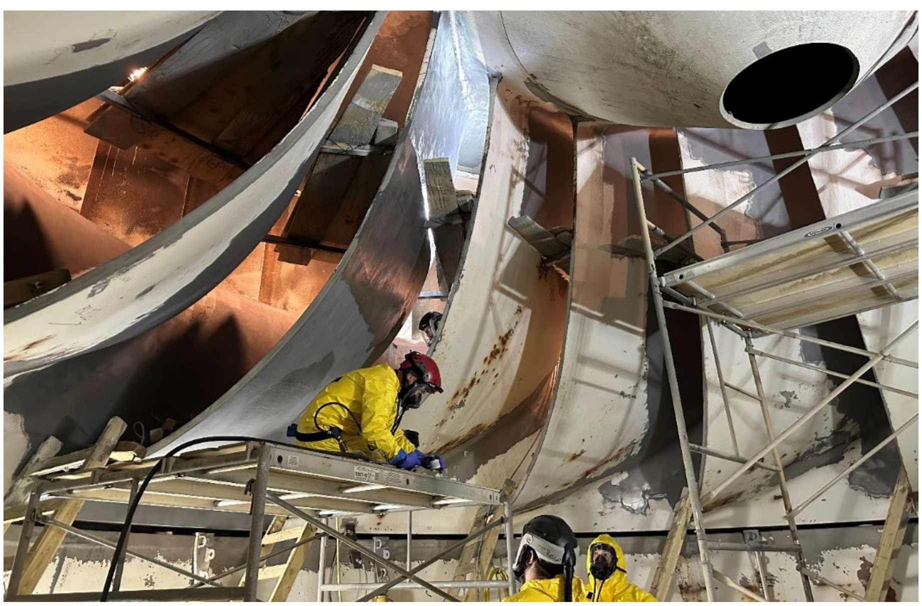
Nathaniel “Nat” Washington Power Plant G21 Turbine Runner Cavitation Resistant Coating Field Trial

Interim Report No. ST-2023-20024-02
Technical Memorandum No. 8540-2023-12

Columbia Basin Project, Washington
Columbia-Pacific Northwest Region



U.S. Department of the Interior

December 20, 2023

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
December 20, 2023	Technical Memorandum	February 6–10, 2023

4. TITLE AND SUBTITLE
Nathaniel "Nat" Washington Power Plant G21 Turbine Runner Cavitation Resistant Coating Field Trial

5a. CONTRACT NUMBER
XXXR4524KS-RR4888FARD2000201/F180A

5b. GRANT NUMBER
N/A

5c. PROGRAM ELEMENT NUMBER
1541 (S&T)

6. AUTHOR(S)
Allen Skaja, Ph.D. Protective Coatings Specialist

5d. PROJECT NUMBER
Interim Report No. ST-2023-20024-02

5e. TASK NUMBER

5f. WORK UNIT NUMBER
86-68540

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Technical Service Center
Bureau of Reclamation
U.S. Department of the Interior
Denver Federal Center
PO Box 25007, Denver, CO 80225-0007

8. PERFORMING ORGANIZATION REPORT NUMBER
Interim Report No. ST-2023-20024-02
Technical Memorandum 8540-2023-12

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Science and Technology Program
Research and Development Office
Bureau of Reclamation
U.S. Department of the Interior
PO Box 25007, Denver Federal Center
Denver, CO 80225-0007

10. SPONSOR/MONITOR'S ACRONYM(S)
R&D: Research and Development Office
Reclamation: Bureau of Reclamation
DOI: Department of the Interior

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
Interim Report No. ST-2023-20024-02

12. DISTRIBUTION/AVAILABILITY STATEMENT

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Cavitation resistant coatings have been used in mild cavitation conditions with mixed results, and rarely lasted more than a few years before needing repair. Laboratory testing identified two commercial polyurethane elastomers with better cavitation resistance than prior coatings used in draft tubes for cavitation resistance. These two elastomers, PE1 and PE2, were selected for field trials on Nathaniel "Nat" Washington Power Plant Unit G21 turbine runner, a severe cavitation environment in which stainless steel weld overlays require repairs of pitting damage on a three-year rotation. The goal of the field trial is to determine if the elastomers can reduce stainless steel cavitation in a severe cavitation environment to lengthen the repair cycle and reduce cost. This interim report documents the surface preparation and coating of Blades 7 and 13 with PE2 and PE1, respectively.

15. SUBJECT TERMS
Turbine runner, severe cavitation, polyurethane elastomer, field trial, cavitation resistant materials

16. SECURITY CLASSIFICATION For Official Use Only:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Allen Skaja
a. REPORT	b. ABSTRACT	THIS PAGE			19b. TELEPHONE NUMBER *(Include area code)*
U	U	U		34	303-445-2396

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.

Nathaniel "Nat" Washington Power Plant G21 Turbine Runner Cavitation Resistant Coating Field Trial

Interim Report No. ST-2023-20024-02
Technical Memorandum No. 8540-2023-12

Columbia Basin Project, Washington
Columbia-Pacific Northwest Region

prepared by

Technical Service Center
Materials and Corrosion Laboratory Group
Allen Skaja, Ph.D. Protective Coatings Specialist

Cover photograph: The team applies adhesive to a turbine runner blade.

Peer Review

Bureau of Reclamation
Technical Service Center
Materials and Corrosion Laboratory Group

Interim Report No. ST-2023-20024-02
Technical Memorandum No. 8540-2023-12

Nathaniel "Nat" Washington Power Plant G21 Turbine Runner Cavitation Resistant Coatings Field Trial

ALLEN SKAJA Digitally signed by ALLEN SKAJA Date: 2023.12.20 08:16:35 -07'00'

Prepared by: Allen Skaja, Ph.D.
Protective Coatings Specialist, Materials and Corrosion Laboratory, 86-68540

GRACE WEBER Digitally signed by GRACE WEBER Date: 2023.12.20 10:05:26 -07'00'

Checked by: Grace Weber
Materials Engineer, Materials and Corrosion Laboratory, 86-68540

DAVID TORDONATO Digitally signed by DAVID TORDONATO Date: 2023.12.20 08:49:45 -07'00'

Technical Approval by: Dave Tordonato, Ph.D.
Materials Engineer, Materials and Corrosion Laboratory, 86-68540

BOBBI JO MERTEN Digitally signed by BOBBI JO MERTEN Date: 2023.12.20 08:32:03 -07'00'

Peer Review by: Bobbi Jo Merten, Ph.D.
Civil Engineer, Materials and Corrosion Laboratory, 86-68540

"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."

Contents

Executive Summary

Cavitation damages hydro-turbines, pumps, pipes, gates, draft tubes, and outlet conduits, resulting in expensive downtime and costly repairs across Reclamation. Stainless steel weld overlays are traditionally used for cavitation repairs on affected structures, which are usually mild steel construction. Cavitation resistant coatings have been used in mild cavitation conditions with mixed results, and rarely lasted more than a few years before needing repair. Laboratory testing of two polyurethane elastomers (which have rubber-like properties) demonstrated superior cavitation resistance compared to prior coatings used in cavitating environments. The laboratory test data indicate these two commercial coating materials, PE1 and PE2, may provide protection in severe cavitating environments when compared to more traditional stainless steel weld overlays. A field trial was deemed necessary to confirm the cavitation resistance of these materials in operational cavitating environments.

Grand Coulee Dam (GCD) supervisors agreed to perform a field trial at the Nathaniel “Nat” Washington Power Plant on Unit G21 turbine runner, which was undergoing cavitation repair maintenance during the week of February 6, 2023. PE2 and PE1 were applied to the downstream sides of Blades 7 and 13, respectively, in Unit G21. The remaining supply of PE2 was used to line the downstream crotch area of the cavitation zone on Blade 8 on March 15, 2023, evaluating a cavitation resistant coating over the corrosion resistant epoxy coating. The Unit G21 return to service date was May 26, 2023, i.e., the field start date for exposure to the severe cavitating environment.

In mid-August, the Unit G21 transformer experienced a failure, and there was a stop in power generation. On October 18, 2023, Grand Coulee staff inspected the PE1 and PE2 cavitation resistant coatings after approximately 1,000 hours of operation. The inspection showed coating damage to PE1 in the most severe cavitation zone on the downstream side of Blade 13, spanning approximately 1 square foot. Approximately 10 square feet of coating damage was noted on PE2 on Blade 7, where the coating was disbonded for five feet along the leading edge. Blade 8 was accidentally omitted from the inspection, but the photos provided indicate complete coating disbondment of PE2 on the leading edge. This indicates PE1 and PE2 experience some cavitation damage in the severe cavitation zone within 1000 hours of operation. Evaluation in other field trials, including moderate cavitation environments, is needed to determine if the coatings prevent cavitation damage for longer operating periods and mitigate the galvanic corrosion cell. Additionally, a longer evaluation period at Unit G21 will determine if PE1 and PE2 provide an advantage in reducing the extent of cavitation damage during the three-year rotation cycle.

Recommendations for Grand Coulee Nathaniel “Nat” Washington Power Plant:
GCD should record the total number of hours Unit G21 operates, record the operating conditions, and conduct periodic inspections. Visual inspection and detailed photos should be taken of the three blades with PE1 and PE2 field trials and directly compared to the same locations on other blades using conventional repair procedures. Provide a scale reference in each image and submit information to the TSC project lead, Allen Skaja (askaja@usbr.gov).

Respirators or powered air purifying respirators (PAPRs) with air purifying cartridges could be worn, removing the need for supplied air lines for future applications of these systems by brush and trowel applications. Chemical-resistant clothing and gloves should always be worn to limit dermal exposure during application.

1. Background

Cavitation damages hydro-turbines, pumps, pipes, gates, draft tubes, and outlet conduits, resulting in expensive downtime and costly repairs across Reclamation. Stainless steel weld overlays are traditionally used for cavitation repairs on affected structures, which are usually mild steel construction. Welding stainless steel to mild steel creates a galvanic corrosion cell in immersion conditions and limits the lifetime of the stainless steel repair, limiting the duration of cavitation protection. Cavitation resistant coatings could be used in combination with stainless steel weld overlays to eliminate the galvanic corrosion cell, thus providing protection and extending the service life of the repairs.

The Research and Development Office's Science and Technology Program funded project number 20024, Field Repairable Materials and Techniques for Cavitation Damage, a laboratory research effort which evaluated 24 commercial coating materials for cavitation resistance [1]. The tests subjected the candidate materials to high-velocity impinging water conditions, and compared the results to type 316 stainless steel, ASTM A36 mild steel, and type 308/309 stainless steel welds overlaid on mild steel. Two polyurethane elastomers (materials with rubber-like properties) showed excellent cavitation resistance in laboratory testing, performing comparable to 308/309 stainless steel weld overlays. The other 22 coating materials exhibited damage within eight hours of the lab testing conditions, compared to 150–250 hours for the two polyurethane elastomers. Table 1 provides typical observations for the varying severity of cavitation intensity.

Table 1.—Cavitation severity levels defined for this research based on the damage level observed in traditional polymer coatings, mild steel, Type 308/309, and 316-series stainless steels after 200 hours of laboratory testing or an estimated 10,000-hour exposure in the field.

Cavitation Intensity	Traditional Polymer Coatings	Mild Steel	Type 308/309 Stainless Steel	Type 316 Stainless Steel
Mild	Volume loss and some complete removal	Light frosting/ minor metal loss	No damage	No Damage
Moderate	Complete removal	Moderate metal loss	Light frosting	No Damage
Severe	Complete Removal	Severe metal loss	Moderate metal loss	Light frosting
Extreme	Complete Removal	Severe metal loss	Severe metal loss	Moderate metal loss

The laboratory results suggest the two top performing polyurethane elastomers, PE1 and PE2, might perform well in moderate or severe cavitation field environments. Field trials were necessary to determine these materials' capabilities and limitations.

A solvent-borne epoxy coating has been the standard coating for the turbine runners at Nathaniel "Nat" Washington Power Plant for more than 20 years. The solvent-borne epoxy coating is not damaged by cavitation on approximately 80 percent (%) of the runner.

2. Field Trial Details

Grand Coulee Dam (GCD) supervisors agreed to perform a field trial at the Nathaniel "Nat" Washington Power Plant on Unit G21 turbine runner, which was undergoing cavitation repair maintenance during the week of February 6, 2023. PE1 and PE2 were applied to the downstream (suction) sides of Blades 7 and 13 in Unit G21. The remaining supply of PE2 was used to coat the cavitation zone on Blade 8 on March 15, 2023, giving it an additional layer of cavitation protection over the corrosion resistant epoxy previously applied.

2.1 Surface Preparation

The turbine runner of Unit G21 was abrasive blast cleaned to white metal, NACE 1/SSPC-SP5, using 16-grit Kleen Blast® abrasive [2]. After cleaning, the surface profile averaged 3.7 mils (mil) on the mild steel areas and 3.6 mil on the stainless steel weld overlay. The manufacturers of

PE1 and PE2 specify a minimum 3.0-mil profile. The cleaned surface of the turbine runner is shown in Figure 1.

2.2 Primer Application

The painting team, consisting of staff from GCD and the Technical Service Center (TSC), applied a ceramic-filled epoxy primer to Blades 7 and 13 on February 4, 2023, using brushes and trowels to coat approximately 210-square foot (sq ft) on the suction side of the blades. Each 3-kilogram kit was applied to a 36-sq ft area with an average dry film thickness (DFT) of 16.6 mil, a maximum reading of 72.6 mil, and a minimum of 1.2 mil. The manufacturer recommended 15 mil thickness. The primer's high viscosity made it difficult to maintain a uniform thickness using brush and trowel application. The GCD staff expressed their preference for spray application because it provides more uniform results. Environmental conditions were not recorded during the primer application.

2.3 Sweep Blast of Primer

Using 16-grit Kleen Blast® abrasive, the primer was sweep blast cleaned to SSPC-SP7, which removed all gloss [3]. The measured surface profile averaged 5.2 mil, exceeding the manufacturer's 2-mil profile requirement. A higher profile in the primer surface could increase mechanical adhesion for the elastomer and decrease the chance of delamination. The sweep blasted primer surface is shown in Figure 2.

2.4 Blade 13 Adhesive and PE1 Application

The team completed the application of adhesive to Blade 13 between 9:30 a.m. and 11:00 a.m. on February 7. Environmental conditions were measured in degrees Fahrenheit (F) before the application and are documented in Table 2 and shown in Figure 3. A thin layer of adhesive was brush-applied to the roughened ceramic-filled epoxy surface. As seen in Figure 4, each employee wore full personal protective equipment (PPE) and isocyanate exposure monitoring equipment; see Section 4. Exposure Assessment During Field Trial for details.

Table 2.—Environmental Conditions Just Before Application of Adhesive to Blade 13

Environmental Condition	Measurement
Relative Humidity	43.3%
Ambient Air Temperature	59.5F
Steel Temperature (Ts)	55.9F
Dew Point Temperature (Td)	37.2F
Delta Ts-Td	18.7F

Environmental conditions were measured at approximately 1:00 p.m., just before applying PE1 to Blade 13. The measurements are listed in Table 3. The manufacturer advises that one kit of

PE1 covers 7.5 sq ft at 40 mil DFT. Before applying PE1, GCD staff prepared approximately 28 grids, 2.5 feet by 3 feet each, to mark the application areas for one kit. However, the team found that one kit covered less than a single grid due to the high viscosity of the mixed system.

Table 3.—Environmental Conditions Just Before Application of PE1 to Blade 13

Environmental Condition	Measurement
Relative Humidity	40.1%
Ambient Air Temperature	62.3F
Steel Temperature (Ts)	56.9F
Dew Point Temperature (Td)	37.8F
Delta Ts-Td	19.1F

PE1 is a two-component polyurethane with a 13-minute pot life. Each PE1 kit was mixed by hand for about three minutes, then troweled onto the adhesive coated surface. Application of PE1 to Blade 13 occurred between 2:00 p.m. and 5:30 p.m. As shown in Figure 5, each employee wore full PPE and isocyanate exposure monitoring equipment.

A visual inspection was performed the following day, February 8. Most of the newly coated area was fully cured, but some areas remained tacky, which prompted inspection of the used product containers. Some of the remaining material at the bottom of a mixing container was not solid, and a few Part B containers had 5–10 milliliters left in the bottom. This suggests some kits were not mixed with the full amount of Part B, resulting in improper mix ratios. Skaja advised the team to wait seven days to allow for complete curing and then conduct a sweep blast over the entire surface to find and remove incompletely cured areas, which would require spot repair following the manufacturer's instructions.

On February 10, the team performed holiday and DFT testing. Holiday testing found no defects in the coating. The coating thickness averaged 46.3 mil with a maximum of 79.3 mil and a minimum of 12.3 mil. Figure 6 shows Blade 13 after PE1 application was finished.

On February 16, the prescribed sweep blast revealed seventeen small spots (3 x 3 inches) that needed repair. Three of the areas were within the cavitation zone and were repaired with PE1 on March 15. The areas outside the cavitation zone were repaired with three coats of solvent-borne epoxy.

2.5 Blade 7 Application

The team completed the application of the same adhesive used for PE1 to Blade 7 between 10:00 a.m. and 11:00 a.m. on February 8. A thin adhesive layer was brush applied to the roughened ceramic-filled epoxy. The team wore full PPE and isocyanate exposure monitoring equipment. At 1:00 p.m., the team was prepared to start application of PE2 when Skaja noticed that Part A of the coating system was a whiteish wax and was no longer a clear liquid as in prior laboratory applications. The team measured the environmental conditions, with results shown in Table 4, and found that the air temperature was below 65F, the crystallization temperature of Part A. The coatings were placed in an office space and the temperature was set to 85F and left overnight, as instructed on the product data sheet.

Table 4.—Environmental Conditions at 1:00 p.m. on February 8th

Environmental Condition	Measurement
Relative Humidity	40.1%
Ambient Air Temperature	60.7F
Steel Temperature (Ts)	55.4F
Dew Point Temperature (Td)	36.4F
Delta Ts-Td	19.0F

On the morning of February 9, PE2 Part A, after heated storage overnight, was a clear liquid again. Environmental conditions for the application of PE2 were recorded and are shown in Table 5. Each member of the painting team donned full PPE and isocyanate exposure monitoring equipment. The team applied a second coat of adhesive between 7:30 a.m. and 8:30 a.m.

Table 5.—Environmental Conditions Measured Before the Application of PE2 to Blade 7

Environmental Condition	Measurement
Relative Humidity	41.7%
Ambient Air Temperature	60.7F
Steel Temperature (Ts)	57.6F
Dew Point Temperature (Td)	37.3F
Delta Ts-Td	20.3F

Since the ambient temperature was still below 65F, heated welding blankets were used to keep the PE2 components between 75–85F. The heated materials were kept near the draft tube door during application. The heat lowered the viscosity of both components and they mixed easily. The team mixed two kits at a time for about 2 minutes each. When the material started to thicken, the mixed coating materials were handed to the three applicators, as seen in Figure 7. Each batch of two kits covered about 12 sq ft. The team used 36 one-pound kits to cover a total of 210 sq ft. PE2 application was completed by 12:00 p.m. on February 9.

On February 10, the team performed holiday and DFT testing. Three pinholes were found on Blade 7 and repaired using one kit of PE2. The kit was heated in a warm water bath for 15 minutes to reliquefy Part A. The final coating thickness averaged 38.7 mil with a maximum of 79.0 mil and a minimum of 9.1 mil. All areas hardened as expected without any tackiness observed. Figure 8 shows Blade 7 fully coated with PE2.

2.6 Blade 8 Application

A few weeks after the field trial applications of PE1 and PE2, GCD staff finished abrasive blast cleaning the G21 turbine runner and applied three coats of solvent-borne epoxy to the remaining areas, including Blade 8. On March 15, they prepared the epoxy in the cavitation zone areas with a bristle blaster, applied the adhesive, and applied the eight remaining kits of PE2, tapering all terminations to minimize risk of disbondment. The primer profile was not recorded for this application.

On March 22, Skaja inspected Blade 8, documented DFT measurements, and took photos. The DFT of the epoxy adjacent to the cavitation zone was 13 mil average. The final coating thickness of PE2 averaged 40.6 mil with a maximum of 81.0 mil and a minimum of 16.1 mil. All areas hardened as expected without any tackiness observed. Figures 9–11 show Blade 8 coated with epoxy and PE2 coated in the cavitation zone.

3. Results and Discussion

3.1 Blade 13 Inspection at 1,000 hours of Operation

In mid-August, the G21 transformer experienced a failure, and there was a stop in power generation. On October 18, 2023, Grand Coulee staff inspected the PE1 and PE2 cavitation resistant coatings after approximately 1,000 hours of operation. The inspection showed PE1 providing adequate cavitation performance on most of the turbine blade, with approximately 1 square foot of coating damage exposing stainless steel weld overlay in the most severe cavitation zone. This location is near the leading edge on the suction side of the blade, as shown in Figure 12. The few corrosion spots are likely from spot repairs of the application defects and inability to control the coating thickness due to brush and trowel application.

3.2 Blade 7 Inspection at 1,000 hours of Operation

The inspection on October 18, 2023, showed approximately 10 square feet of coating damage in the PE2 repair due to cavitation and delamination between coats, with some areas exposing stainless steel weld overlay in the severe cavitation zone near the leading edge on the suction side of the blade as shown in Figures 13–16.

3.3 Blade 8 Inspection at 1,000 hours of Operation

The inspection on October 18, 2023, accidentally omitted Blade 8 so there is no data at 1,000 hours of operation. The only documentation is showing the leading edge on the upstream side of the blade, with small black specks of coating remaining, shown in Figure 17. Blade 8 will be inspected during the next outage.

3.4 Key Findings

The field trial applications of PE1 on Blade 13 and PE2 on Blade 7 revealed two main challenges, offering good lessons for future use of these materials on a large surface area.

First, for Blade 13, improper mixing ratios of PE1 Parts A and B resulted in areas of incompletely cured product. This was likely due to the relatively short, 13-minute pot life of the system, which presents a challenge for field application. This may have been exacerbated by the exposure assessment requirements—such as wearing full PPE and additional monitoring equipment—which were time consuming and cumbersome. The trial for PE2 did not result in areas of incompletely cured product, which has nearer to a 45-minute pot life. Additionally, PE1 was applied late in the afternoon, requiring the team to work past normal business hours, which increased the stress on individuals to get the materials applied. To improve results in future application, some suggestions are:

- provide a demonstration on how to handle quickly-curing coatings,
- allow team members to perform/witness practice applications and discuss feedback and what can be improved,
- and begin application early enough in the day so that work can be completed within normal business hours.

The second challenge, shown on the Blade 7 application, was that the team had not considered the crystallization temperature of PE2 Part A. It is possible that the use of two coats of adhesive on Blade 7 due to the initial crystallization of PE2 Part A contributed to the disbonded coating. This challenge was overcome by warming up the materials to 85F overnight or by reliquefying for 15 minutes in a warm water bath. An additional solution could be to place the materials in heating blankets prior to use. Future applications can utilize heating blankets or 5-gallon pails of warm water to keep the product components at an appropriate temperature for application.

The application of PE2 on Blade 8 was installed by field personnel with a corrosion resistant primer. The exact details of the application were not documented, and the inspection at 1,000 hours of operation omitted Blade 8. Thus, the outcome is unknown at this time. More information on results, challenges, and lessons learned from the Blade 8 application of PE2 can be determined after the next inspection.

4. Exposure Assessment During Field Trial

PE1 and PE2 are polyurethanes containing 4,4’ methylene diphenyl diisocyanate (MDI) , a known carcinogen and sensitizer. Concern over the health hazards of MDI requires the highest level of worker protection. Full PPE for the painting team included supplied air respirators, Tychem suits, and chemical resistant gloves.

The OSHA and NIOSH permissible exposure limit (PEL) of MDI is 5 parts per billion (ppb) time weighted average (TWA) for an 8-hour shift. The ceiling PEL is 20 ppb for a 10-minute exposure. MDI monitoring for isocyanate exposure was done following NIOSH Method 5521 to monitor the breathing zone for the two applicators and the two people mixing [4]. The team used Gilair Plus air monitoring pumps equipped with Iso-Check® cassettes (for the TWA) and Asset® tubes (for the ceiling PEL). The tubes were kept on for the duration of the application. Once the application was complete, the tubes were removed and processed for shipping to a lab for analysis. For PE1 application, cassettes showed non-detectable for the adhesive and coating systems; the tubes showed a maximum exposure of 0.17 ppb during the adhesive application, and non-detectable for the coating application. No Iso-Check or Asset tube data was collected for PE2 due to the postponed application.

In addition, when entering the turbine runner, each team member wore a Morphix Company's SAFEAIR colorimetric badges for toluene diisocyanate/MDI near the breathing zone for a visual assessment to monitor exposure of everyone. The colorimetric cards were used to indicate immediately if any individual was exposed and at what concentration. None of the colorimetric cards showed exposure. One card was dabbed with the adhesive product to confirm it was working, and it turned bright red.

For future applications of these systems in similar conditions, respirators or powered air purifying respirators (PAPRs) with air purifying cartridges could be worn in lieu of supplied air lines when brush or troweling is used. Note that chemical-resistant clothing and gloves should always be worn to limit dermal exposure.

Work and safety plans and the Job Hazard Analysis (JHA) for this field trial are available for internal Reclamation employees. Contact TSC project lead, Allen Skaja (askaja@usbr.gov), for more information.

5. Conclusions

- Two polyurethane elastomer coating materials were successfully applied to Blades 7, 8, and 13 of Unit G21 turbine runner. Lessons learned and best practices on application are documented in this report for future reference.
- Initial field results show that after 1,000 hours of operation, the PE1 and PE2 coatings show small areas of damage, found mostly on the areas of the turbine runner blade that experience the most severe cavitation environment.
- Blade 7 showed the most damage, approximately 10 square feet, possibly due to having two adhesive coats because of the PE2 Part A crystallization delaying the application one day to re-warm. Blade 13 showed approximately 1 square foot of damage. The damage location was consistent for both and in the severe cavitation zone near the blade leading edge.
- Overall, the field application could have improvements for ease of application of the polyurethane elastomers, the adhesive, and the epoxy primer.
- Air monitoring pumps equipped to assess TWA and PEL showed non-detectable respirable or below the action level for MDI according to OSHA and NIOSH limits during the application of the adhesive and PE1.

- Visual MDI-indicators worn by each member inside the turbine runner showed no exposure to respirable MDI during the applications of the adhesive, PE1, and PE2.

Recommendations for Grand Coulee Nathaniel “Nat” Washington Power Plant:

- Grand Coulee should record the total run time of Unit G21 and operating conditions. GCD should allow inspections during outages to determine the coating system performance. Detailed photos showing location and scale should be taken and provided to the TSC project lead, Allen Skaja (askaja@usbr.gov).
- For future applications of these systems in similar conditions, respirators or powered air purifying respirators (PAPRs) with air purifying cartridges could be worn in lieu of supplied air lines when brush or troweling is used. Note that chemical-resistant clothing and gloves should always be worn to limit dermal exposure.

6. References

[1] A. H. C. Skaja, "Investigation of Polymeric Elastomers for Cavitation and Erosion Resistance," in *AMPP Conference*, Denver, CO, 2023.

[2] NACE/ SSPC, "NACE 1/ SSPC-SP5 White Metal Blast Cleaning," NACE/ SSPC, Houston, TX, 2006.

[3] NACE SSPC, "NACE 4/ SSPC-SP 7 Brush-off Blast Cleaning," NACE SSPC, Houston, TX, 2006.

[4] National Institute of Occupational Safety and Health, "NIOSH Method 5521 Isocyanates, Monomeric," NIOSH, Washington, DC, 1994.

7. Figures


Figure 1.—Typical condition of surface preparation at 308 stainless steel weld overlay/mild steel transition.

Figure 2.—The surface of Blade 13 primed with ceramic-filled epoxy, shown after sweep blasting.

Figure 3.—Measurement of environmental conditions on Blade 13 prior to the application of adhesive.

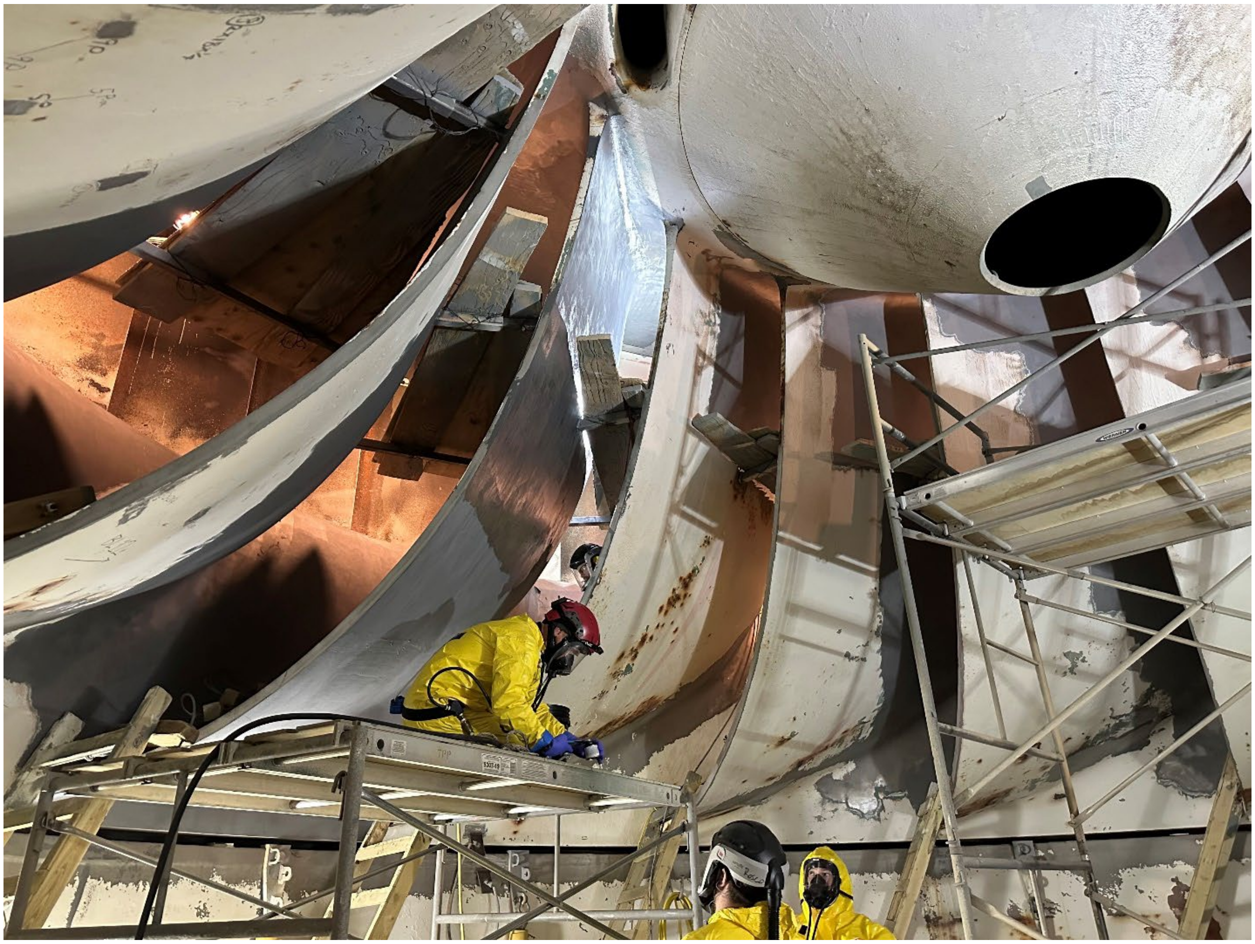


Figure 4.—The team applies adhesive to Blade 13.

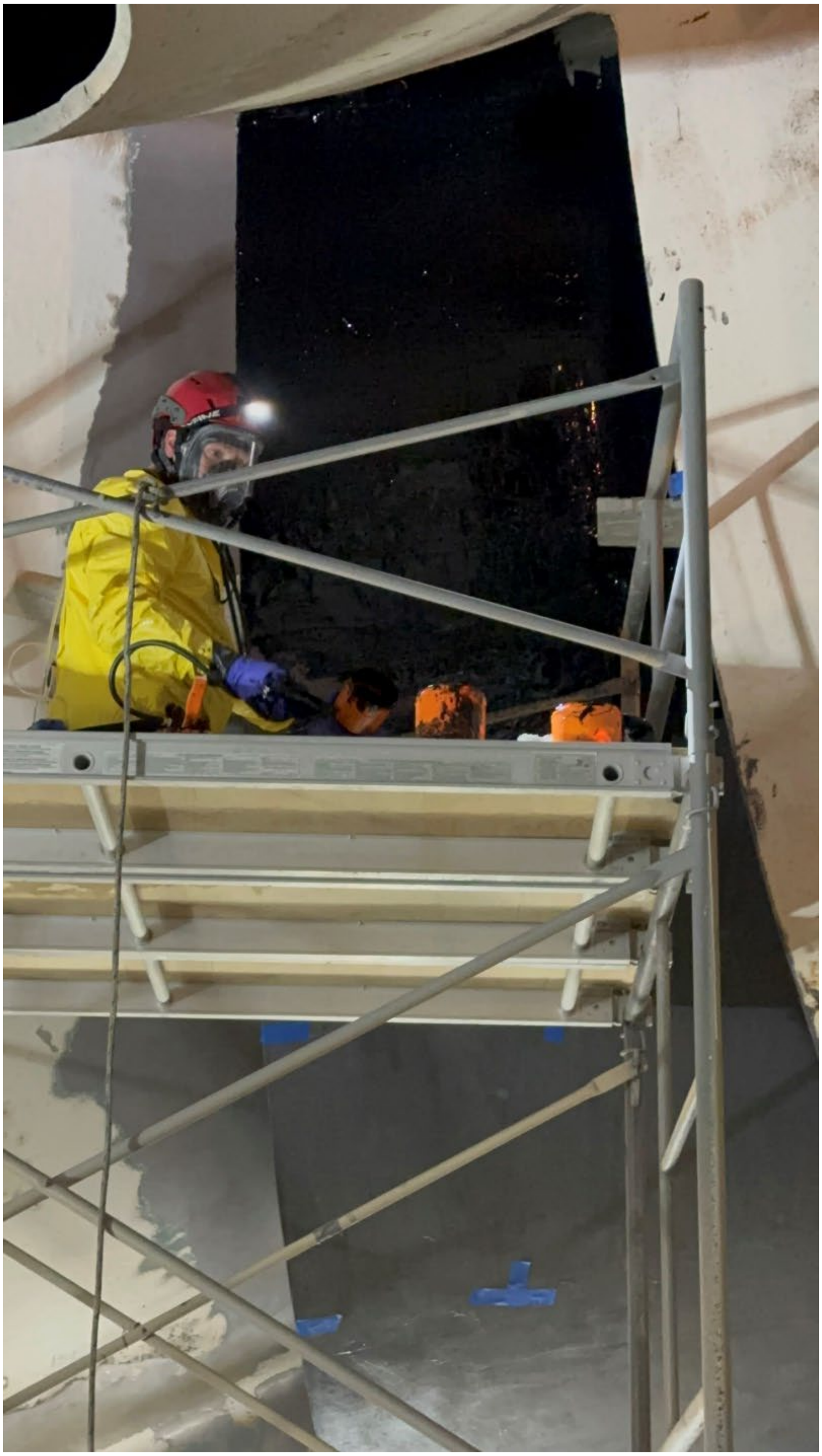


Figure 5.—Application of PE1 to Blade 13.

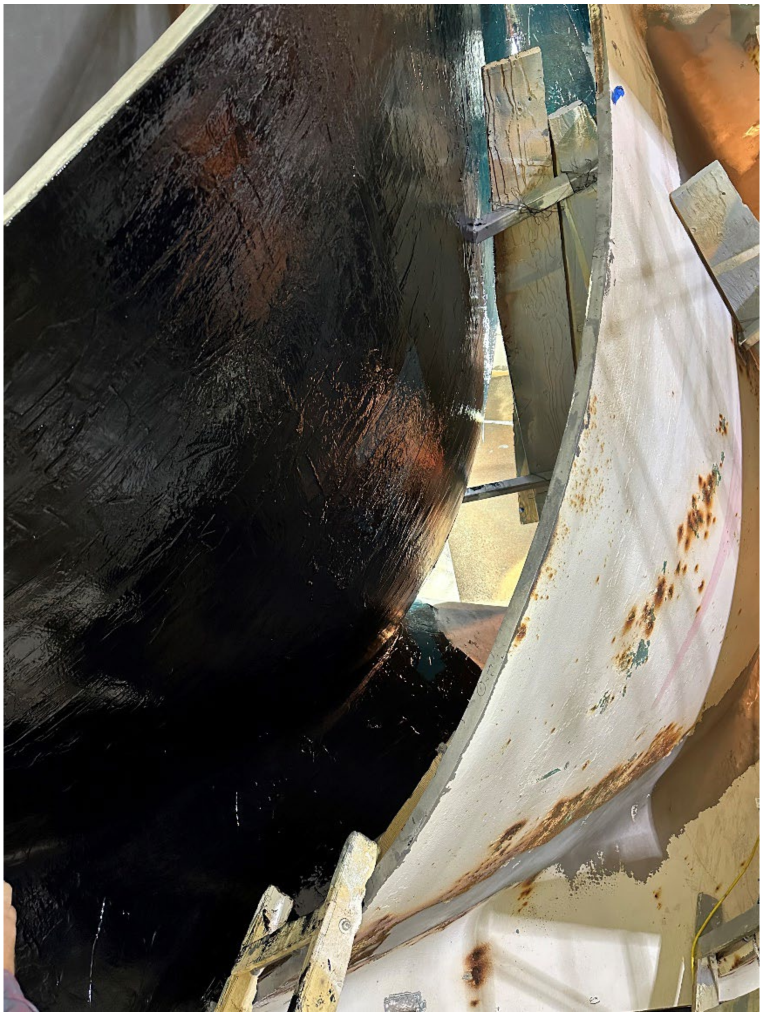


Figure 6.—Blade 13 shown coated with PE1.

Figure 7.—Application of PE2 to Blade 7.

Figure 8.—Blade 7 shown coated with PE2.

Figure 9.—The cavitation zone of Blade 8 shown coated with solvent-borne epoxy and PE2.

Figure 10.—The cavitation zone of Blade 8 shown coated with solvent-borne epoxy and PE2.

Figure 11.—The cavitation zone of Blade 8 shown coated with solvent-borne epoxy and PE2 before exposure.

Figure 12.—Cavitation damage on leading edge suction side of PE1, approximately 1 square foot of damage. The gray color is from application defects that were repaired with an epoxy.

Figure 13.—Blade 7 after 1,000 hours of operation. The PE2 failed by cavitation and delamination on leading edge with approximately 10 square feet of damage. The rust spot near the center of the blade is from the welded brace that was removed for the platform and repaired using an unknown procedure.

Figure 14.—Close-up of Blade 7 after 1,000 hours of operation. The PE2 failed by cavitation and delamination on leading edge.


Figure 15.—Close-up of Blade 7 after 1,000 hours of operation. The PE2 failed by cavitation and delamination.

Figure 16.—Close-up of Blade 7 after 1,000 hours of operation. The PE2 failed by cavitation and delamination.

Figure 17.—Leading edge of Blade 8 showing the applied PE2 almost completely gone, with only a few specks of the black coating still remaining after 1000 hours. No photos are available of the downstream side of the blade shown in Figure 11.