Revisiting Acryloid B-72®/Paraloid™ B-72 and Barrier Numbering: A Pilot Study and Suggested Solutions for Archaeological Museum Collections

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Final Report

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Executive Summary

This report provides the final results of the collaborative study of the acrylic resin Acryloid B-72®/Paraloid™ B-72[1] for barrier coat numberings conducted by the National Park Service's (NPS) Southeast Archeological Center (SEAC), and the Institute for the Preservation of Cultural Heritage (IPCH) at Yale University. Methods of analysis at IPCH included impregnating samples of B-72 with water, measuring the absorption of water into the solution at different percentages of relative humidity, and examining the disruption of permanent ink with the B-72 solution. The museum technicians at SEAC field-tested the suggested mitigations of these issues, as reported by IPCH. SEAC evaluated higher and lower concentrations of the Paraloid B-72 and acetone solution, different brands of ink, and different instruments for marking. The details of the tests from IPCH can be found in their final report "Investigation into causes and mitigation of defective object labels based on Acryloid/Paraloid B-72," which is being submitted alongside this report. The details from the testing at SEAC can be found later in this report.

Results show that the current method of marking artifacts at SEAC and the guidelines in the NPS Conserve-O-Gram need to be revised to allow for greater flexibility in different climates. In particular, the 25% concentration of B-72 recommended by the NPS[2] is too viscous to allow for a smooth base coat of B-72 to be applied. For a top coat, the 25% solution also does not allow for a smooth application nor does it allow the top coat to dry quickly enough to keep the catalog numbers legible after marking. Furthermore the recommended use of Higgins® Black Magic® permanent ink for marking needs to be reconsidered in light of other inks on the market. Recommendations to fix these issues include:

1. Decreasing the percent concentration of B-72 to allow for a smooth application of base and top coat.
2. Increasing the number of base and top coat applications to protect the surface of the artifact and the label.
3. Training staff in mixing the solution and correcting viscosity as needed during labeling.
4. Checking the ingredients/formula of permanent ink for changes over time.
5. Testing new instruments for marking for better ink application and less potential for damaging the surface of the artifact.
6. Regular housekeeping/checking supplies for aging or decay and discarding supplies as necessary.
7. Better temperature and humidity control in the laboratory environment.

Finally, the report acknowledges that the analysis has limitations. Some of these limitations include: not testing pre-made B-72 solutions from NPS recommended companies, not testing the proposed changes outside of a lab setting, not testing the thermo-plasticity of the B-72 resin, and not testing all possible additives to the solution. This report, therefore, does not represent the final authority on the subject but provides conservative and practical suggestions for using and adapting B-72 for barrier numbering.

[1] For the sake of simplicity this will be called simply B-72 throughout the paper.
[2] Sullivan and Cumberland 1993, 1.

Introduction

The National Park Service's (NPS) Southeast Archeological Center (SEAC) catalogs, stores, and maintains the archeological collections of the national parks located in the Southeastern United States and territories. Every year the museum technicians at SEAC are responsible for cataloging roughly 100,000 artifacts, and from this number approximately 30,000 individual specimens are labeled with a unique catalog number. SEAC follows the guidelines and procedures for the barrier coat method of numbering set forth by the NPS Museum Handbook[3] for labeling all stable artifacts (with the exception of human remains, paper, textiles, historic plastics and resins, metal, and some natural history specimens), and has adapted the guidelines set forth in the 1993 National Park Service Conserve-O-Gram No. 1/4[4] to fit its needs. This report will provide answers to the original problems outlined below and illustrate the additional issues that were discovered during the course of the research. What fundamentally remains the same, however, is the museum staff's concern that the catalog numbers are applied efficiently and that the catalog numbers are both legible and stable for long term storage. Necessity has compelled technicians to deviate slightly from the national guidelines, which also is a concern, and therefore, these differences are identified and explained in this study.

SEAC uses the acrylic resin Acryloid B-72®/Paraloid™ B-72 in acetone for its barrier numbering. B-72 is widely known as a stable and durable lacquer for conservation, and it is recommended by curators and conservators over other lacquers because it ages well, prevents absorption of labeling inks into the artifact, has thermo-plastic properties, and is easily removable.[5] The numbering technique as outlined in the NPS Conserve-O-Gram is used nationwide by the National Park Service and also used by historical societies,[6] conservation centers,[7] independent trusts,[8] and museums.[9] B-72 is also used to attach labels to stable artifacts.[10] Institutions in the United States[11] and abroad[12] are reliant, in part, on the guidance put out by the National Park Service on the use of B-72, and thus, the results of this study of B-72 may have far-reaching effects on almost every major collections-based endeavor (NPS and non-NPS), with particular emphasis on collections held in warm and moist climates.

The long-standing verbal instructions and methodological practice of artifact numbering at SEAC is as follows: the museum technicians apply B-72 acrylic resin/acetone (10% solution) to an artifact by

[3] Byrne et al. 2000, J: 1-J: 18.
[4] Sullivan and Cumberland 1993, 1-4.
[5] Chapman and Mason 2003, 382; Davidson and Brown 2012, 99; Koob 1986, 7; Koob 1996, 1; Sullivan and Cumberland 1993, 1. Koob (1996) cautions using B-72 in both cold and hot environmental conditions due to the thermoplastic properties of B-72. In cold environments, Koob (1996, 1-2) discovered that a B-72 adhesive (containing fumed silica) would set slowly and not bubble very much. In hot conditions, around 104 degrees Fahrenheit and above, the adhesive will not harden because of its thermoplastic properties.
[6] Delfino 2000b, 4-6.
[7] National Park Service Handbook and Conserve-O-Gram series are referenced at the Northern States Conservation Center (http://www.collectioncare.org/collection-care). Dana Senge, pers. comm.
[8] Chapman 2008, 5-6.
[9] Utah State University Eastern Prehistoric Museum 2014, 4.
[10] Carrlee 2011. SEAC does not use this technique.
[11] Hill-Festa 2010, 1.
[12] National Museums Liverpool 2014; Preservation and Heritage Management Department of the Powerhouse Museum. No Date.

placing a small rectangle of thin, clear lacquer (for light objects) or white lacquer (for dark objects) on the object using a small cap brush. The lacquer is allowed to dry, and then the park acronym and catalog number are written on the spot with permanent black ink (Higgins® Black Magic®) using a Crow quill or Rapidograph® pen. The ink is allowed to dry thoroughly, and the number is coated with clear lacquer to protect it.[13] For the last seven years, when the author has worked in the curation division at SEAC numbering artifacts using this methodology, the B-72 lacquer has sporadically had the problems outlined below.[14] The unpredictable appearance and increasing regularity of these problems, both at SEAC and nationwide[15] prompted this study.

Though there are many reports on the utility and stability of B-72 as a protective coating for wooden artifacts,[16] as a glue for mending ceramics[17] and marble,[18] and for restoring glass[19] no publication has yet addressed the practical problems of using B-72 for barrier numbering, though these issues are widely known. The museum technicians at SEAC, as well as from other regional offices and national parks,[20] have noted bubbling of the lacquer and dissolution of catalog numbers. These problems result in the barrier coat of B-72 being repeatedly removed and reapplied and the catalog numbers being re-written. These practical problems, therefore, affect the efficiency in which the numbers are applied as well as SEAC's accountability to the public. Additionally, these repeating problems cause increases in cost and time-on-task with diminishing results. An investigation of the practical problems and their solutions are needed in order to make sure that NPS staff members are being cost effective, that the NPS Conserve-O-Gram is revised to reflect years of practical application

[13] Byrne et al. 2000, J: 4.

[14] Pers. comm. with former museum technicians indicate that the bubbling issues with B-72 has been previously noted and documented. Some documentation of the ink issue was discovered in the working office files of SEAC curator, Richard Vernon. In this documentation from 1998 the problem of the inked numbers smearing and dissolving is noted as well as the long drying time of coats of the B-72 solution. The suggested reasons for these issues were that: the relative humidity in the lab was high or that the acetone had absorbed a lot of water vapor. This documentation's hypotheses have been proven in this study.

[15] Others witnessing the same problems were identified through pers. comm. (email and conversation) with staff from SEAC, Intermountain Region Museum Services Program, Western Archeological Conservation Center, Harpers Ferry Center, The Corning Museum of Glass the National Park Service Museum Management Program, Fort Smith National Historic Site, Florida Bureau of Archaeological Research, Indianapolis Museum of Art, Institute for the Preservation of Cultural Heritage, Yale University, Mammoth Cave National Park, and Timucuan Ecological & Historic Preserve. The issue was independently brought up during the course of this study in conference calls with the Southeast Region curators and the National Park Service Registrar Committee.

[16] Rivers et al. 2003, 565; Wilson 1998, 2.

[17] Koob 1986, 7-9.

[18] Podany et al. 2001, 27-28.

[19] Koob et al. 2011, 2-4.

[20] Pers. comm. (email and conversation) with: staff from SEAC, Intermountain Region Museum Services Program, Western Archeological Conservation Center, Harpers Ferry Center, The Corning Museum of Glass, Midwest Regional Office, National Park Service, the National Park Service Museum Management Program, Fort Smith National Historic Site, Florida Bureau of Archaeological Research, Indianapolis Museum of Art, Institute for the Preservation of Cultural Heritage, Yale University, Mammoth Cave National Park, and Timucuan Ecological & Historic Preserve.

experience in warm and humid climates, [21] and that the NPS is maintaining its commitment to the American public to protect and preserve our nation's treasures.

Due to time and personnel constraints at SEAC, as well as to foster scientific independence, the research conducted under this agreement was undertaken by individuals with a background in conservation science. Dr. Paul Whitmore and Dr. Rui Chen from the Institute for the Preservation of Cultural Heritage (IPCH) at Yale University were contracted to test the B-72 solutions and the ink used at SEAC for artifact numbering. Dr. Whitmore is the director of the Aging Diagnostics Lab and a professional conservation scientist with experience in polymer stability, protective coatings, and ink stability. Dr. Chen is a senior conservation scientist with research interests in nanoparticles and sensors that determine chemical and physical deterioration of artifacts and art over time.[22] The results of their scientific research are presented in a separate report, and their conclusions will contribute to the development of best practices for the conservation and preservation of archeological objects from the national parks.

Challenges in Research

There were two problems that were not anticipated by this study but which should be addressed since they were identified during the course of the research. The first problem encountered was that there appeared to be no universal recommendations on the B-72 solution formula. There is a variety of different concentrations of B-72, as well as other lacquers, inks, and techniques that are used to apply catalog numbers. In researching for this project, respected sources in the field of archaeology and conservation, which offer guidelines on using B-72,[23] could not provide a universal standard. It also became clear during the study that the NPS Conserve-O-Gram is not as widely used or strictly adhered to as originally assumed. The NPS Conserve-O-Grams should be considered more of a guide rather than the rule when looking at the wider world of barrier coatings and artifact labeling. This report represents a first effort to revisit NPS guidelines, something we should strive to do more often as we simultaneously seek collaborative input domestically and internationally.

Additional research and methodological problems included SEAC's deviation from the 1993 Conserve-O-Gram. For artifact labeling, the 1993 National Park Service Conserve-O-Gram No. 1/4 recommends using a 25% lacquer (B-72 and acetone solution) instead of a 10% lacquer solution used at SEAC. The replacement was made because the 10% lacquer required more base coats to protect the surface of the artifact than the 25% solution.[24] The National Park Service's Curatorial Services Division in Harpers Ferry, West Virginia supplied the 25% lacquer to the parks in both the clear and white formulas

[21] Since the 1993 National Park Service Conserve-O-Gram No. 1/4 on B-72, which is now 20 years out of date.
[22] Institute for the Preservation of Cultural Heritage (IPCH) at Yale University 2015. Chen, 2015. Whitmore, 2015.
[23] Brady et al. 2016. For example, the Society for Historical Archaeology website (Brady et al. 2006) recommends using a 15% solution of B-72 in acetone for the bottom coat and a 20% solution of B-67 in naphtha for the top coat in barrier coat numbering. It also cites the NPS Conserve-O-Gram for further information for labeling artifacts. In personal communication with Stephen Koob (Corning Museum of Glass), he suggested not using toluene to the acetone solution. He also recommended 5-10% ethanol be added to the B-72 solution for hot climates or possibly methyl ethyl ketone. Both would prevent a film from forming on the B-72 solution which would allow the acetone to evaporate evenly and prevent the formation of bubbles.
[24] Sullivan and Cumberland 1993, 2.

at the time of the 1993 Conserve-O-Gram.[25] The white formula, at that same time, contained 0.01 percent of toluene to keep the titanium dioxide pigment in suspension.[26] For at least the last seven years, however, the museum technicians at SEAC have used a 10% solution of both clear and white lacquer that was made in house, rather than supplied. Furthermore, the white lacquer has not contained toluene due to human health hazards.[27] During the course of this research internal memos and recipes regarding SEAC's 10% lacquer solution were found,[28] but current practices based on institutional memory did not consistently adhere to these internal memos.

The internal memo states that the 10% solution should be measured by weight to make 1L of the clear lacquer. The white lacquer should be made to only a 0.5L volume and include 1 ml of toluene. The B-72 crystals should also be suspended from cheesecloth and allowed to dissolve into the solution over two to three days. [29] From the author's training and SEAC's institutional memory, the actual practice at SEAC has involved making a 10% solution of the clear lacquer (total volume being 0.75L) by mechanically dissolving the B-72 crystals using a magnetic stirrer for 2-4 hrs.[30] One of the museum staff members who has made the solution most often has used a volume/volume measurement, and another museum staff member who would rarely make the solution would use a weight/weight measurement.[31] The white lacquer has typically been made at a 10% concentration up to 0.5L. The B-72 crystals are dissolved in the same manner as the clear lacquer. The titanium dioxide is not always measured, and the amount is sometimes estimated based on the opacity of the white tint.[32] Again, too, toluene has not been used in the formula for over seven years.

Concerning the application of the lacquer, the 1993 Conserve-O-Gram states that the application of the base layer of B-72 lacquer should take approximately 30-60 seconds to dry to the point it can accept an inked number.[33] The museum staff at SEAC has noticed that the 25% solution and the 10% solution can take much longer than this to completely dry. Sometimes the drying time is over 24 hours, and sometimes it is over a week. Additionally, the museum technicians from SEAC, as well as from other regional offices and national parks,[34] have noted that the 25% lacquer bubbles when the

[25] Sullivan and Cumberland 1993, 3
[26] Sullivan and Cumberland 1993, 1
[27] LabChem 2012, 6. ScienceLab.com 2013, 4-5.
[28] Formulas for Lacquer Used for Numbering Museum Objects 1999, 1. Pers. comm. (email) between Jessica Johnson and Richard Vernon, 1998. See also Hortenstein 1994, though Mr. Vernon recollected that the use of a 10% B-72 solution was actually used before 1992.
[29] Formulas for Lacquer Used for Numbering Museum Objects 1999, 1.
[30] Richard Vernon, pers. comm. The use of the magnetic stirrer came about during the tenure of contract curator, Joan Day, at SEAC, which post-dates the Conserve-O-Gram and the internal memos. Ms. Day recommended the magnetic stirrer in order that the B-72 solution be mixed more quickly and more thoroughly than using the cheesecloth method. The internal memos on recipes and techniques were never updated with the mechanical stirrer, but the technique was adopted in oral instruction.
[31] The author observed each staff member's technique for measuring the B-72 crystals and acetone. The author determined that both staff members were accurately obtaining a true 10% solution of the lacquer.
[32] Charles Sproul pers. comm. Hank Kratt, pers. comm.
[33] Sullivan and Cumberland 1993, 2.
[34] Terry Langford pers. comm. Terry Langford, the curator at Mammoth Cave National Park began experiencing the problem when she switched her supplier of pre-made B-72. She is experiencing problems with the products from

base coat or top coat is applied to an artifact. The staff at SEAC has also noticed that the 10% lacquer sometimes bubbles as well. The bubbles that develop when the lacquer is applied and the long drying time interfere with the application of inked catalog numbers. For the bubbling problem, the base and top coat must be removed and reapplied, and this process may repeat a number of times. For the long drying time, the tip of the pens used for marking can pull or tear the base coat resulting in the base coat having to be removed and reapplied. [35] This tear in the barrier also makes the artifact surface vulnerable to ink coming into direct contact with it. The bubbling and long drying time issues are, therefore, of high concern in identifying a more effective solution, and this report suggests ways in which these issues can be mitigated.

An intersection with the bubbling and drying time problems is found in the problem of catalog numbers dissolving when a top coat of the lacquer is applied[36]. It has been suggested that the cause of the numbers dissolving is from too much acetone in the B-72 solution since the acetone in the top coat causes the base coat to slightly dissolve.[37] Thus, higher concentrations (15%-25%) of B-72 lacquer have been seen as the answer to this issue. The museum technicians, however, have noticed that these higher concentration lacquers produce bubbles in the top coat and still take a long time to dry (as noted earlier). Thus, the entire numbering process has to be re-done with the base coat being removed and reapplied and the catalog numbers re-written. These practical problems, therefore, affect the efficiency in which the numbers are applied and the accountability of SEAC to the public.

The author also reached out to employees at the Higgins Ink company to see if there had been any changes to the ink recipes since Higgins ink was first adopted for use. This information, however, is proprietary knowledge and the company would not divulge it. The company did, however, supply MSDS sheets when requested, but these documents did not go into specific detail regarding active and inactive ingredients. Thus, the author did not know during the course of the study if the ink formula had changed since the 1993 NPS Conserv-O-Gram No. 1/4 was composed. Additional studies that focus exclusively on permanent, pigmented ink would be necessary to determine the role of ink variability. Finally, in consultation with Supervisory Museum Specialist, Hank Kratt at SEAC[38] and Associate Manager of Museum Conservation Services and Collections at Harpers Ferry Center, Linda Blaser[39] the author

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Light Impressions and University Products, and has had the issue year-round. The staff at Mammoth Cave National Park was using Pigma pens from Light Impressions and Gaylord and is now using Micron pens (email). Pers. comm. (email) with Anne Lewellen, the curator at Timucuan Ecological and Historic Preserve, indicates that she has had issues using Pigma pens on lacquer with numbers not drying or numbers dissolving when a top coat is applied (email). Pers. comm. (email) with Harpers Ferry Center, Indianapolis Museum of Art, Western Archeological and Conservation Center, the National Park Service Museum Management Program, Southeast Archeological Center.

[35] The museum technicians at SEAC use an assembly line style of numbering to speed up the labeling process. Base coats are applied to a series of objects, and the base coats are left to dry. The technician then moves to ink other artifacts that had previously been given a base coat that was allowed to dry. Top coats of B-72 are applied to artifacts that had previously been numbered, and the ink allowed to dry.

[36] See Whitmore and Chen 2017, 12 for embedded video.

[37] Museum Technician, Charles Sproul pers. comm. Museum Specialist, Hank Kratt, pers. comm.

[38] Hank Kratt, pers. comm.

[39] Linda Blaser pers. comm.

requested permission to try other pigment based inks in addition to the Higgins Ink, which was the standard ink used during numbering.

Background Research

In order to better define the parameters for study, SEAC staff conducted informal testing of the supplies that were already used for numbering. Eight tests were run exploring the different B-72 concentrations and fluctuations in the ambient environment naturally caused by the Florida climate in the spring, summer, and fall. A more controlled test of the ambient environment was not possible, but based on the readings from Koob,[40] ambient temperature may cause issues with bubbling. The lacquer used for these tests had been mixed in 2014 and 2015 and used for the annual numbering process. There had been sporadic failure (bubbles and dissolving numbers) of this lacquer. Two new bottles of Higgins Black Magic ink were also used to see if there was a difference in how a bottle of newly-opened ink fared against a bottle of ink that had been used in the previous year.

The informal tests on the lacquer used three different concentrations of B-72: 20%, 15% and 10%. The tests that looked at the 20% concentration of clear B-72 lacquer saw that bubbles appeared in the base and top coat and that the inked numbers dissolved regardless of the ambient environment (ranging from 75.9° F and 50% RH [inside] to 91° F and 37% RH [outside]). Drying[41] times ranged from 5 minutes to 24 hours. The 15% concentration of clear B-72 lacquer did not develop bubbles in the base or top coat, though the inked numbers partially dissolved. The ambient environment for these tests was measured at 75.9° F and 50% RH to 87° F and 48% RH. Finally the 10% concentration of clear B-72 lacquer did not develop bubbles in the base or top coat, and the numbers were only partially dissolved. The ambient environment ranged from 75.9° F and 50% RH to 87° F and 48% RH. It was noted, however, that the lacquer from these same 10% concentration bottles had previously caused bubbling and dissolving. No clear reason was identified for why the lacquer worked during the informal experiments, but not consistently during numbering in the previous years.[42] The results indicated that exploring the concentration may be a fruitful avenue of research.

In consulting with a number of southeast national parks and conservators during the course of the study, the author learned that the NPS is currently purchasing premade material lacquer from University Products, Light Impressions, and Gaylord for premade material lacquer.[43] The curator at Mammoth Cave National Park, however, has experienced problems with the premade lacquer, particularly the products from Light Impressions and University Products. The curator noticed that the lacquer was not drying quickly and the numbers were smearing when a top coat was applied. The curator noticed this problem when the lacquer containers were changed from “nail polish bottles” to short round bottles, and the curator suspects there is too much acetone in the lacquer. An excess of acetone is, therefore, believed to be the reason for the slow drying time and smeared numbers, but the curator did not know the percent concentration of the pre-made lacquer. The curator also mentioned

[40] Koob 1996, 1-2.
[41] “Dry” was defined as the base coat of B-72 no longer being tacky to the touch.
[42] Failures and successes were seen to be sporadic, with no clear indication of cause.
[43] There may be other suppliers as well, but these three suppliers were mentioned by the national park staff, who were consulted.

that the pre-made lacquer in the short bottles from Light Impressions and University Products thickened over time (even when the bottle was kept tightly sealed when not in use) and discolored. Once this change occurred, the lacquer was no longer used.[44] When the author researched the companies that supplied Mammoth Cave National Park with their B-72 lacquer, she discovered that Gaylord does not list the concentration of B-72[45] and University Products lists their B-72 as a 25% solution.[46] Since this information was supplied near the end of the study, and the project was focused specifically on the materials and methods used at SEAC, these pre-made lacquers were not tested. The author would strongly recommend future researchers to investigate this line of inquiry.

Two different bottles of Higgins Black Magic ink were also used for the informal tests at SEAC. One bottle was newly opened, and the other had been opened and used in the previous year. The newly opened ink smelled strongly of ammonia and consistently failed (i.e. the inked numbers dissolved) during informal tests. The previously opened ink smelled organic and sporadically failed during these informal tests. The ink from both bottles was applied using a Rapidograph pen with a 0.35 nib, and care was taken to make sure the pen had been completely cleaned between the uses of both inks. Finally, it was observed that the newly opened bottle of ink appeared 'thinner' in its application than the organic smelling ink, which produced a thicker and more opaque line. The nature of the ink odor was subject to investigation and the results are discussed below.

Additionally, during the course of this study the author learned more about the types of pens and inks used for marking cataloging numbers on objects within the parks. Mammoth Cave National Park has used Pigma pens from Light Impressions and Gaylord for numbering, but they are currently using Micron Pigma pens. No issues were acknowledged with the pens for numbering from their curator.[47] Timucuan Ecological and Historic Preserve staff are also using Pigma pens, but the curator notes that the numbers marked with these pens regularly smear upon applying the top coat.[48] The variability between pen types was not test systematically, since these issues with these specific pens were also discovered during the course of the research and pens were not the principal focus of the research.[49] Some opportunistic observations were made about pen use and are discussed in the following section.

Methods and/or Materials

Initially, this project's methodology was designed in three steps in order to best isolate the variables that could have been causing the problems with the B-72 and the inked numbers. The first

[44] Terry Langford pers. comm. Terry Langford, the Curator at Mammoth Cave National Park stated that letting the base coat dry overnight solved their problems with a tacky base coat and smeared numbers. He did not mention the issue of bubbling, and tackiness was not an issue considered for this study since the museum technicians at SEAC have never attempted to write the numbers on a tacky surface.
[45] Gaylord Archival. 2016.
[46] University Products 2016.
[47] Terry Langford pers. comm.
[48] Anne Lewellen pers. comm.
[49] Alten 2010. In this informal study, Alten concluded that Micron Pigma pens should not be used for numbering barrier coats because the ink beads and smears.

step involved numbering at SEAC using the current materials, methods, and typical laboratory environment on eight common surface types (terra cotta, glazed earthenware, porcelain, wood, glass, chert, sandstone, and bone). The second step was designed to focus on the physics of numbering, looking at the surface tension of B-72 and the displacement of air in the eight materials. The third step would test a range of solution variables and environmental conditions using the conclusions drawn from the first two steps.

After the informal testing described above, and consultation between SEAC and IPCH staff, SEAC sent the IPCH researchers samples of the 10% clear lacquer and samples of the inks from the informal testing. A bottle of white 10% lacquer, made in the previous year, was also sent. Upon receipt of these items and in early tests and discussions, it became apparent that the three step process would not be the best course of action. The division of research became as thus: SEAC tested laboratory variables to find a practical solution with the resources available to staff there (step one). Dr. Whitmore and Dr. Chen focused on the chemical and physical properties of the lacquer and ink on glass slides only, since failure of the lacquer and ink occurred most often on glass or glassy artifacts (steps two and three), and recommended how the lacquer and ink failures could be solved. The SEAC staff then translated these suggestions into practical action, given the limitations of the laboratory facility (ambient conditions, labeling supplies, accepted numbering methodology, etc.) Although the three step methodology had to be adjusted, each methodological step was explored and the results were shared between the museum technicians at SEAC and the staff at IPCH.

At SEAC, four museum technicians took part in the experiment. Each technician brought a different level of skill to the numbering process, ranging from eight years' experience to less than six months. Employees with a range of skills were involved in order to determine if skill/familiarity played a role in the tendency for the lacquer and/or ink to be problematic. After initial observations, of all the variables, skill in applying the lacquer or ink seemed to be least likely to be causally related to the problems observed, although some related aspects, such as quantity of base or top coat applied, could have a role. These lacquer and ink problems were present in the tests done by all technicians. The results of testing the speed, pressure, and amount of B-72 applied as a base and bottom coat were also did not seem to be causally related since each technician's technique was markedly similar. Each technician loaded the cap-brush with a small 'bead' of B-72 present on only one side of the brush, and applied the 'bead' to the surface.[50]

Each museum technician followed the SEAC guidelines for labeling (10% solution) and used Rapidograph pens that had been thoroughly cleaned and filled with Higgins Black Magic ink. The lacquer and ink used in testing were drawn from the same material as that sent for research at the IPCH facilities. All of the technicians' work stations are located within the curation lab, but these workstations are variously placed in the room. Some workstations are near to external doors, and others are near air conditioning vents. Each technician labelled objects as normal and reported to the author successes and failures as they occurred.

[50] The technique was overall the same as the personal application of nail polish.

Using the current method, each technician, unsurprisingly, reported failures. The type of pen was then switched to a Crow quill, which delivers a greater quantity of ink than the Rapidograph, since it was thought that a greater volume of ink might prevent the numbers from dissolving. The numbers, however, continued to dissolve. During the alternating between Rapidograph pens and Crow quill pens, the author noticed that the numbers that had dried to a matte finish would remain legible after a top coat was applied. The numbers that had dried to a glossy finish, though, would not. These observations were reported to the researchers at IPCH, who were conducting experiments using the same ink. There was no discernable reason why numbers would dry to either a matte or glossy finish. Multiple types of surfaces were tested by SEAC museum technicians in the exploratory phase, as well as both inks (ammonia/organic) and drying times, but there was no apparent link between surface, ink type, drying time, and the appearance of matte versus glossy appearances.

The author continued investigating the ink recipes to determine if the cause of the odors was a variable to the sporadic ink failure. In exploratory testing, though, both inks performed similarly sporadically, and based on these observations the author did not think that the odor was causal factor for the ink failure. The author contacted representatives at Higgins Ink, researched the ink recipe ingredients, and compared the recipes and ingredients to other brands of pigmented permanent ink. The results of these investigations are explained in more detail below, but the author suggested that a different ink should be tested in case new inks on the market could perform better than the ink in current use. The ink that was selected, based on the recommendations of Linda Blaser from National Park Service's Curatorial Services Division in Harpers Ferry, West Virginia was Koh-I-Noor, Ultradraw 3085-F, Black India Rapidograph ink. This ink was approved for testing because it is pigment based, which is a requirement for ink used in numbering [51]and listed as waterproof for paper and film.[52]

While the technicians waited for the arrival of the Koh-I-Noor ink, they experimented with Zig millennium pens using the 10% B-72 base coat and top coat. When the base coat and top coat did not bubble, the Zig millennium pens produced legible numbers that did not dissolve. The type of ink that was pre-filled in the Zig millennium pens is unknown. The technicians, however, found that the act of marking was difficult with the pens (i.e. the ink did not flow smoothly and it took time to get the ink to flow). The line thickness of the pens was, furthermore, very thin.

Once the Koh-I-Noor ink arrived, the Rapidograph pens were emptied of the Higgins inks and thoroughly cleaned before the Koh-I-Noor ink was added. Each technician experimented with this ink using the 10% solution that had been sent to the IPCH facilities using SEAC's labeling procedures. When there were no bubbles in the base or top coat, this ink dried very quickly (between 30 seconds and 10 minutes) to a matte finish. The numbers did not dissolve when a top coat was applied. The ease of marking and the line thickness were the same as the Higgins ink since each technician was using the same hardware (Rapidograph pens and crow quills). Every time a number was applied with the Koh-I-Noor ink, the numbers remained legible.

[51] Linda Blaser pers. comm. Dye-based inks were not approved for testing.
[52] Koh-I-Noor 2016.

With legible numbers due to the Koh-I-Noor ink, the museum technicians at SEAC continued testing various B-72 solution concentrations for the bubbling issues. Suspecting that the previously made 10% solution may not be accurate due to the evaporation of acetone, the author made a new 10% solution (750mL) of B-72 (clear and white) using SEAC's techniques. The museum technicians then proceeded to apply base coats, numbers, and top coats as described above. The newly made B-72 10% solution was noticeably less viscous than the B-72 10% solution made prior to these experiments and sent to Yale for testing. Bubbling was still sporadically present in both the clear and white lacquer. The drying time for the new 10% solution was also less than that for the older 10% B-72 solution, and all base coats were dry within one working day (max. 8 hrs.). Some objects required more than one base coat, however, due to uneven surfaces in order to apply a number safely on the object. The number of base coats applied was not uniform, and each museum technician used as many base coats as they felt were necessary to protect the object from marked numbers (between 1-5 coats or more). Finally, the numbers written with the Higgins ink dissolved when a topcoat of the fresh 10% solution was applied, but the numbers written with the Koh-I-Noor ink remained legible.

Following the tests of a freshly made 10% B-72 solution, the author made a 25% concentration of clear B-72 as recommended by the NPS Conserve-O-Gram though without toluene due to health hazards. Bubbling in the base coat occurred in every test, and the bubbles were considerably larger than the bubbles that occurred in the 10% solution tests. The 25% solution also took much longer to dry than the 10% solution. In some tests, the base coat (with bubbles) was still tacky after drying for a 24 hour period. One base coat was typically sufficient to protect the object's surfaces, but in some cases two coats were required for uneven surfaces. The numbers written with the Higgins ink dissolved when a topcoat of the 25% solution was applied, but the numbers written with the Koh-I-Noor ink remained legible.

Concurrently with the investigation of the ink and the different concentrations of B-72, Whitmore and Chen reported two different behaviors observed in the Higgins Black Magic ink. One problem occurred with the old ink, and they reported that the binding medium had settled, coagulated, or was otherwise not flowing easily from the pen (i.e. the ink was "lean"). When a top coat of B-72 was applied (20% solution concentration made in their lab), the ink would disintegrate into chunks and float in the top coat, essentially erasing or dissolving the mark that was made. The new ink behaved in a different way. There was enough binding medium for the ink to adhere to the base coat and remain cohesive, but when the top coat was applied, the ink thinned though it was still legible (faintly). The top coat was slightly dissolving the bottom coat, causing the ink to be driven deeper into the base layer. The issues with both inks occurred at low relative humidity conditions, but the problems were more pronounced with relative humidity over 50%.[53]

Since the quick solution to the old ink was to simply not use it any longer for numbering, Drs. Whitmore and Chen provided two possible solutions to the new ink problems. The first suggestion was to dry the top coat faster by increasing the acetone (thereby decreasing the solution's concentration). A quicker evaporation time for the acetone may prevent the base coat from re-dissolving when the top

[53] Paul Whitmore pers. comm. August 12, 2016. Whitmore and Chen 2017, 7, 13-14.

coat was applied. If the base coat did not re-dissolve, then the ink should remain legible when applied. This suggestion for the ink may also solve the bubbling problem,[54] which they believed may be caused by a 'skin' forming on the surface of the base coat, trapping small pockets of air as the base coat dried.[55] The other solution for the ink, as well as the bubbling, may be to slow the penetration of acetone from the top coat into the bottom coat by adding solids to the base coat such as fumed silica or titanium white. Dr. Whitmore and Dr. Chen did not agree on this second possible solution due to the added variable that it presented and the issues with user control.[56] The author agreed with their concerns, and was aware of the reluctance to use the white B-72 solution at SEAC unless absolutely necessary.[57]

After these suggestions were made to increase the speed of evaporation and drying, a lower concentrated solution of B-72 was tested. The author mixed a 5% B-72 solution (without toluene, both clear and white) and the museum technicians proceeded to test this solution as described elsewhere. No bubbles occurred upon applying a single base coat, but this was believed to be too thin to protect the surface of the objects during the numbering process. Multiple base coats were laid down in order to produce a safe thickness, but placing coat after coat of base material diminishes the efficiency of the numbering process. As a single top coat, the 5% concentration did not dissolve the numbers written in the Higgins ink or Koh-I-Noor ink. When abrasion was applied to the numbers after the top coat had dried, however, the technicians were able to easily remove the numbers. This lower, 5% concentration is therefore not a practically viable solution to the problems presented by the B-72 solution or the inks.

Recommendations

Using the NPS Conserve-O-Gram guidelines (1993) for the 25% concentration of B-72, the bubbling of the base coat was frequent, causing the museum technicians to remove and reapply the base coat a number of times. When a smooth base coat without bubbles could be achieved, the drying time of the base coat also was lengthy (more than 30 seconds but upwards of 24 hours) when using the 25% solution. Based primarily on the difficulties in obtaining a smooth base coat without bubbles, the 25% solution concentration is not recommended for numbering artifacts.

Following the SEAC guidelines (1999 or older) prescribing a 10% solution, the bubbling in the base coat was sporadic and less than that of the 25% solution. The bubbling occurred with less frequency when a fresh batch of 10% solution was made and used. It is therefore thought that the previously made B-72 10% solution was actually greater in concentration than 10%, and this unknown yet elevated concentration caused the bubbling. With a freshly-made B-72 solution, the drying time was also less than for the previously made B-72 10% solution. Additionally, the relative humidity in the

[54] Ibid.
[55] Paul Whitmore pers. comm. May 6, 2015.
[56] Paul Whitmore pers. comm. August 12, 2016.
[57] Richard Vernon pers. comm., Hank Kratt pers. comm. It has been recommended to only use the white B-72 solution when an object is completely black and opaque. If the catalog number can be visible by looking through the object, in the case of dark glass, or by tilting the object under a microscope, the clear B-72 is encouraged to be used.

curation lab may have played a role in the frequency of the bubbling base coat and in the drying times, with the relative humidity possibly exacerbating these problems.

Two types of pens were tested using Higgins Black Magic ink: Rapidographs, and Crow quill. A third type, the Zig millennium—also was used with its unidentified pre-filled ink. The Zig millennium pens worked most regularly, but it was difficult to get the ink to "flow" smoothly and produce a thick line for each number. The Zig millennium pens and their unidentified ink content are therefore, not recommended for use.

In testing, it appeared that the Higgins Black Magic ink sporadically and frequently failed because the ink expired, the ink remained wet, and/or the ink was dissolved by the B-72. The author researched other inks to test to see if they would remain legible during numbering, and after consulting with SEAC staff, as well as other curators within the NPS, was granted permission to test the Koh-I-Noor, Ultradraw 3085-F, Black India Rapidograph ink. When combined with the SEAC guidelines for number (10% solution, made freshly in-house), this ink remained legible on the artifacts. Thus, the Koh-I-Noor, Ultradraw 3085-F, Black India ink is recommended over Higgins Black Magic ink for numbering artifacts.

Regarding the inks, the author contacted representatives at Higgins Inks and obtained current MSDS sheets for their Black Magic ink, which had been used for numbering objects at SEAC. Unfortunately, the MSDS sheets did not contain as thorough a description of ingredients as hoped.[58] When the author asked about the specific ingredients, Barb Willard, a Higgins ink representative stated that the binder for the Black Magic ink is shellac and that the ink is water-based and uses pigment for the colorant.[59] No other ingredient information was forthcoming. Regarding the ingredients for the Koh-I-Noor, Ultradraw 3085-F, Black India Rapidograph ink ingredients, the author found more information. The MSDS for this ink listed ammonium hydroxide, phenol, ethylene glycol, water, carbon black, and shellac. Carbon black makes up between 7-9% of the total solution, and shellac makes up around 6-8% of the solution.[60]

The term "water-based shellac," as Dr. Whitmore explained, means shellac dissolved in ammonia, which may keep the shellac in solution for the ink and explains the smell from the Higgins Black Magic ink. He also noted that acetone is an excellent stripper of shellac and expressed surprise that the B-72 solution had not dissolved the numbers before since the solvent is acetone.[61] Dr. Whitmore also suggested that the organic smelling ink was pungent because the ammonia may have also served as the ink's fungicide and had either dissolved or failed in some other way. He recommended that ink that no longer smelled like ammonia should be thrown away.[62] Since it was not

[58] Chartpak 2008, 1-2. Chartpak 2015, 2. Sanford Corporation 2001, 1-2. No ingredients were listed in Sanford Corporation 2001 or in Chartpak 2008. Chartpak. 2015, 2 lists ammonium hydroxide, bensixothiazolinone, polyethoxylated beta naphthol, and aniline dye are listed.
[59] Barb Willard pers. comm.
[60] Koh-I-Noor 2003, 1.
[61] Whitmore and Chen 2017, 12-16. The embedded videos and explanation of acetone dissolving the "old" organic ink and the "new" ink are explained in more detail in their report.
[62] Paul Whitmore pers. comm. August 18, 2016. Barb Willard pers. comm. August 12, 2016. Ms. Willard had also suggested that the antimicrobial agent had stopped being effective, which was the cause of the organic odor. She

known when the organic smelling ink was opened prior to this study, it is possible that its organic smell and loss of ammonia may be related to the shelf-life of Higgins inks.

Understanding the shelf life of ink is pertinent to this study in order to help establish best practices for artifact labeling. In communications with Barb Willard at Higgins Ink, she stated that the shelf life of an unopened bottle of Higgins Black Magic ink that is kept in a cool and dark place is approximately 10 years. Once a bottle has been opened, the shelf life is typically two years, but the shelf life can be shortened through improper storage such as fluctuations in temperature and the introduction of dust, which allow for mold growth (the organic smell).[63] Thus, as suggested by Dr. Whitmore and Dr. Chen, old ink should not be used and new ink should be mixed well (shaking the bottle) to ensure that the binder is not settled out.[64]

The author discussed these findings with Joan Bacharach, the senior curator at the Museum Management Program, National Park Service and editor of the NPS Conserve-O-Grams in order to see what would be necessary in order to revise the NPS Conserve-O-Gram (1993).[65] Ms. Bacharach recommended that this report's findings be tested by others, and currently there is an inter-disciplinary team being assembled at Harvard to continue investigating the issues raised here. Thus, while an update to the Conserve-O-Gram was initially planned as a deliverable for this project, an update is pending additional testing with Ms. Bacharach's team.[66]

Conclusions

This study attempted to provide answers to common problems using B-72 for barrier numbering at SEAC. The problems, namely that of the lacquer bubbling and the inked numbers dissolving, have plagued the numbering process for approximately 20 years but have not been investigated in that time due lack of resources. The solutions to the problems were approached in two ways: the first was scientific, using the expertise of Dr. Paul Whitmore and Dr. Rui Chen in material science and conservation; the second was practical, using the experience of the museum technicians at SEAC who are responsible for ensuring timely and legible numbering and who are the employees positioned to notice and correct problems as they occur.

Concerning the B-72 lacquer (clear and white), the research suggests that a solution concentration of a maximum of 10% is good for numbering in humid climates. This percent concentration allows for the acetone to evaporate without the formation of skin on the surface of the base and top coat. The skin that occurs at higher levels of percent concentration traps evaporating acetone and creates bubbles in the B-72 lacquer. Technicians using the 10% solution should be trained to recognize when the 10% solution has exceeded the original 10% concentration due to evaporation of

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also mentioned that the ammonia will "gas off" in time, and the ink can also smell organic when this happens. Ms. Willard did not, however, state that the ammonia was the antimicrobial agent.

[63] Barb Willard pers. comm. August 12, 2016.

[64] Paul Whitmore pers. comm. August 12, 2016.

[65] Joan Bacharach pers. comm. September 12, 2016.

[66] Joan Bacharach pers. comm. January 11, 2017.

acetone within the bottle and thin the lacquer as needed (using varying measurements in mL of acetone added to the solution). Technicians should also be trained to determine how many base coats of the B-72 solution are needed in order to create a barrier that protects the surface of the artifact from bleed-through of the ink as well as abrasion by the marking instrument during numbering. It was not possible to create a completely standardized process for applying the B-72 and the numbers, so emphasis is placed on training and increasing familiarity of all technicians involved in the process.

Regarding the ink, the correspondence and research suggests that there are more variability and longevity issues associated with permanent, pigmented inks than previously realized. This primarily concerns the Higgins Black Magic Ink that has been used by SEAC for approximately 20 years. Proper storage of unopened and opened ink, as well as regular housekeeping for expired ink, is necessary to ensure that the ink, when used, is of the highest possible quality. Using old or expired ink was one contributing cause to the ink dissolving when a top coat was applied. One other cause was the percent concentration of the solution, as mentioned above. A final possible contributing cause could be the recipe used for the ink itself, and if any recipe changes have occurred within each bottle of ink[67]. Our research suggests the Higgins Black Magic Ink may no longer be the best available ink for numbering. When the other variables of the percent concentration of the B-72 and a new bottle of ink were considered, the numbers continued to dissolve. Thus, a different ink was tested, Koh-I-Noor, Ultradraw 3085-F, Black India Rapidograph ink. This Koh-I-Noor ink did not fail in any of the tests, and it is therefore recommended that the technicians at SEAC use this ink rather than the Higgins ink since it conforms to the necessary conservator guidelines.

Finally, in order to maintain efficiency and longevity for numbering artifacts using the barrier coat method, the percent concentration of B-72 should stay around 10% for both base and top coats, and the inks that are being used should be replaced or changed if the ink dissolves. This will require all technicians to be trained in order to recognize when failures in the B-72 and ink occur, and the upper level supervisory staff being supportive of proactive changes in order to protect the artifacts and provide better accountability. Once these issues have been addressed on a local level, it is the author's hope that the cataloging and numbering process will be efficient and sustainable.

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[67] The quality control of each bottle of ink in unknown, and only anecdotal observations were accessible. There may be variations to the recipe as well that are un-reported at this time. Future investigations should investigate how the ink is made and if there are any deviations or errors to the ink recipe that make it to the market.

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