Issue Paper: Extracting Sound Recordings from Damaged Lacquer Discs
By Yuri Shimoda

> [T]here remains a considerable part of the audiovisual legacy that is still stored on its original carriers. The main reason is obviously the lack of funds. But also lacking is a sense of urgency to complete the digitisation of content. There is an ever-decreasing time window to complete the digitisation process before the small pool of equipment in operable condition required for the replay of traditional formats vanishes. Today, this window is estimated to be between 10 to 15 years.[1]

During the first month as an MLIS student at UCLA, I attended a talk on collection sustainability organized by the UCLA Digital Archiving Collective. In his segment, Curator of UCSB Library's Performing Arts Collection David Seubert brought up the "ever-decreasing time window" left to digitize audiovisual materials held by cultural heritage institutions in an even more vivid way: a looming cloud of obsolescence hanging over archivists' heads. The image remained with me throughout my first year of coursework, but the dark cloud actually confronted me face-to-face this summer while I was conducting work for my internship at the Library of Congress (LC) National Audiovisual Conservation Center (NAVCC).

In 2011, Universal Music Group (UMG) donated over 200,000 master recordings to the LC. Within the collection were historic works by artists such as Bing Crosby, Louis Armstrong, the Andrews Sisters, Ella Fitzgerald, and Les Paul. Many of these tracks were recorded onto thousands of 16-inch instantaneous lacquer discs with either a glass or aluminum base. Those created during the 1940s served as the focus of my LC Junior Fellows project over the summer at the NAVCC. I processed all of the glass discs in the UMG collection, in addition to several boxes of aluminum-based lacquers, for a grand total of about 2,000 discs during my 10 weeks in Culpeper, Virginia. Many of the discs were broken, extremely fragile, or showing other signs of

---

[1] Dietrich Schüller and Albrecht Häfner, eds., *Handling and Storage of Audio and Video Carriers (IASA-TC 05)* (London: International Association of Sound and Audiovisual Archives, 2014): 5.

degradation. Some days, the carpet in my cubicle would be littered with pieces of sound in the tiny black specks of lacquer that had flaked off of discs or my desk would be piled with boxes of broken/cracked lacquers. My interaction with these delicate sound carriers prompted the decision to write about rescuing audio material from discs in my portfolio. I wondered if there were measures that could be taken to prevent or stave off degradation. How could archivists ensure that the culturally significant speeches, songs, and other sounds these discs contained be preserved? If a disc was fractured into several pieces, was there something an archivist could do to rescue its recordings?

As with all organic compounds, analog sound recordings are inevitably going to start decomposing. Due to its unique physical composition, the *ARSC Guide to Audio Preservation* states that "the most fragile commonly encountered audio format is the lacquer disc. … All lacquer discs are at risk of deterioration and are a preservation priority."[2] Extracting sound recordings from damaged lacquer discs is a pressing task for audio archivists, as this format is inherently at risk, and lack of action will lead to loss of valuable cultural materials. This paper explains why optical playback is the best means of rescuing these recordings on damaged discs and compares existing methods.

History

The lacquer type of instantaneous disc was introduced in the 1920s and underwent a series of transformations as it remained the dominant sound recording format until the late 1940s. Instantaneous discs could be used to record and replay signals in real time without a

---

[2] Harrison Behl, "Audio Formats: Characteristics and Deterioration," ed. Sam Brylawski et al, *ARSC Guide to Audio Preservation* (Eugene, OR: Association for Recorded Sound Collections; Washington, DC: Council on Library and Information Resources and the Library of Congress, 2015), 17 and 21.

complicated electrotyping and pressing method. While earlier cylinder technology used for ethnographic and commercial recordings could only capture around two minutes of sound, these discs could hold fifteen minutes of audio per side. The most widespread type of instantaneous discs were lacquer transcription discs, ranging in size from seven to sixteen inches in diameter. The soft lacquer coating of these discs consists mainly of cellulose nitrate that is plasticized with castor oil or camphor on a metal (usually aluminum), glass, cardboard, or paper base.[3] During World War II, aluminum was rationed, so disc manufacturers could only produce lacquers with glass substrates. "Most of these discs are unique,"[4] carrying early radio broadcasts and other, ethnographic field recordings, historically important meetings and court trials, home recordings, or irreplaceable studio sessions like the aforementioned UMG masters. Lacquer discs replaced cylinders in both the home recording and commercial audio industries by the mid-1930s and remained the dominant format until the rise of magnetic tape in the late 1940s.[5]

Urgent Need for Preservation

Knowing how to identify a lacquer disc in a collection is of the utmost importance for all archivists, as is the ability to tell the difference between glass, metal, or paper/cardboard-based discs and awareness of the format's deterioration issues for several reasons: the medium's instability, uniqueness of their content, and their prevalence in collections. It is for these reasons that this paper points to an active approach (copying from one physical format to another) to

---

[3] National Archives & Record Administration, "Format Guide to Sound Recordings," archives.gov, October 2014, accessed January 31, 2019, https://www.archives.gov/files/preservation/formats/pdf/format-guide-to-sound-recordings.pdf. These discs are sometimes referred to as 'acetates,' which is actually a misnomer that might be attributed to early lacquers needing to be played with acetate needles. See Michael Biel, "History of Instantaneous Recording, Part II: The Lacquer Disc" (presentation, ARSC Conference, Syracuse, New York, May 22, 1998).

[4] Schüller and Häfner, 11.

[5] Behl, 21.

preservation versus a passive one (storing the materials in ideal conditions to slow down/halt deterioration).[6]

To understand the need for active preservation, it is necessary to investigate the instability of the format. As evidenced by the large amount of broken and/or delaminating discs that crossed my desk this summer at the NAVCC, the clock is ticking; the amount of time left to preserve lacquer discs continues to dwindle. Lacquers, most notably glass-based discs that become brittle and more subject to cracks and breaks with time, are literally falling apart. In addition to scratches, groove wear, and surface contamination (dirt, dust, and mold), all lacquer discs are susceptible to two forms of deterioration: delamination and exudation.

As cellulose nitrate reacts with oxygen and water vapor, it produces acids, which cause the lacquer coating of a disc to begin to shrink. Since its metal or glass substrate is not able to shrink, the lacquer begins to crack and come apart from the base.[7] This decomposition is known as laminate separate or delamination. Once delamination begins, it cannot be reversed and becomes accelerated in warmer and more humid storage environments. The condition is eventually going to spread across a disc's surface. Delaminating or cracked/broken discs must be stored horizontally to alleviate stress from gravity and to prevent further damage. Several institutions, such as Stanford University,[8] Indiana University (IU) Bloomington,[9] and, as mentioned, the LC, have created customized broken disc housing for such storage.

---

[6] Bob Pymm, "Preservation of Audiovisual Media: Traditional to Interactive Formats," eds. G.E. Gorman and Sydney J. Shep, *Preservation Management for Libraries, Archives and Museums* (London: Facet Publishing, 2006), 99 and 105.

[7] Schüller and Häfner, 11.

[8] Brandon Burke, "Designing a Housing for the Horizontal Storage of Cracked or Broken Phonograph Discs," *ARSC Journal* 25, no. 1 (Spring 2018), 28-40.

[9] Elise Calvi, "Floating Disks," *E. Lingle Craig Preservation Lab Blog*, March 9, 2016, https://blogs.libraries.indiana.edu/craiglab/2016/03/09/floating-disks/.

Exudation occurs when the plasticizer in a disc begins to break down and its acid components begin to appear on the surface of the lacquer in the form of a white, greasy powder. Acid exudation can be mistaken for mold since it manifests in the form of a white powder, but is distinguished by its greasy texture. There have been studies to determine what kind solution might work best to remove exudation from a disc without damaging it, such as Marcos Sueiro Bal and Jeff Willens' survey of treatments presented in a poster at the 2018 Audio Engineering Society International Conference on Audio Archiving, Preservation & Restoration.[10] While cleaning a lacquer's surface with castor oil, mineral oil, or solutions like Disc Doctor removes signs of exudation from the disc as indicated by the study, it is only a temporary fix. Once exudation begins, there is no way to permanently stop it from reappearing on a disc's surface and covering its recorded contents. As I witnessed this summer at the NAVCC, an exudating disc can be played, but it must be cleaned until all signs of the white powder are gone. No amount of washing can prevent the acid exudation from continuing to eat away at the disc, though. Soon enough, its surface will once again become covered by the greasy white spots.

Instantaneous discs were popular because of their convenience, but they were only meant to be played so many times. The rarity of the often-unpublished recordings that the lacquers contain is also an argument for the urgent need to digitally reformat them for posterity. A final reason is their prevalence in collections.

> Tens of thousands of lacquer discs in archives in the United States remain unpreserved. In the very near future, custodians of these collections will have to decide whether to preserve these recordings or lose access to their content. … [There is] meaning that attaches to sound recordings after the passage of time, a

[10] Marcos Sueiro Bal and Jeff Willens, "Survey of Suggested Treatments for Removing Acidic Exudation from Vintage Lacquer Discs" (poster presentation, Audio Engineering Society International Conference on Audio Archiving, Preservation & Restoration, Culpeper, Virginia, June 28-30, 2018).

> meaning that can be bestowed by their creators, by historians, or by society. … if the proper care or preservation of sound recordings is postponed until their significance is realized, it may well be too late. … it is impossible to preserve everything, and it may be similarly impossible to anticipate which recordings will assume greatest significance in the future; consequently, the individuals making choices among collections to be preserved must be sufficiently knowledgeable to assess which recordings most merit attention.[11]

In 2014, AVPreserve and the Northeast Document Conservation Center (NEDCC) performed an assessment of existing audio items held in institutions across the United States. They found that 177 institutions (academic libraries, non-profit broadcasting organizations, state and large city historical societies, special libraries, archives/museums) had over two million items classified as "grooved media" in their collections.[12] This survey was not able to provide counts for specific grooved media carriers like lacquer discs, so I decided to ask four institutions that I knew had at least a small amount of the medium for a current approximation of their holdings.

As of January 2019, the LC Recorded Sound Section maintains 3.6 million recordings at the NAVCC; over 370,000 of them are lacquer discs. The Head of the Recorded Sound Section, Caitlin Hunter, states that some of these lacquers have been transferred to open reel tape in the past, and a portion of those tapes have been digitized.[13] However, only approximately 5,600 of the lacquer discs have directly been digitally preserved. According to Jeff Willens, sound engineer for New York Public Library's (NYPL) Audio and Moving Image Preservation Labs,

---

[11] Rob Bamberger and Sam Brylawski on behalf of the National Recording Preservation Board, *The State of Recorded Sound Preservation in the United States: A National Legacy at Risk in the Digital Age* (Washington, DC: Council on Library and Information Resources and the Library of Congress, 2010), 23 and 35.

[12] Bertram Lyons, Rebecca Chandler, and Chris Lacinak, *Quantifying the Need: A Survey of Existing Sound Recordings in Collections in the United States* (Brooklyn, NY: AVPreserve, 2014), 8.

[13] Caitlin Hunter, email message to Yuri Shimoda, January 28, 2019.

there are approximately 28,000 lacquers system-wide.[14] Only 10-percent of these discs have undergone preservation reformatting. In a January 21, 2019 email interview I conducted with Adam Tovell of the British Library, he shares that all of the approximately 22,000 lacquer discs in their collections have been digitized, save for about 20, which he says "are too damaged to attempt to play." There are just over 8,100 lacquer discs held by Indiana University, and the institution's Mass Digitization & Preservation Initiative (MDPI) Audio Preservation Engineer Melissa Widzinski says they have yet to digitize about 3,500 of them.[15] Around 100 of these have not been digitized due to cracks, delamination, or warpage.

Solutions: Mechanical

Using a turntable and stylus is the ideal means of listening to any disc because this is how they were meant to be played. It has taken decades to develop the mechanical components within a playback system. It is easy to take for granted how much work has gone into housing the magnets, rubber suspension arm, and plastic parts within a head cartridge, let alone the technology that has gone into manufacturing tiny styli able to effectively read the material in a groove at affordable prices for consumers. However, it is not possible to even attempt to play cracked, broken, or delaminating lacquer discs mechanically without proper training and expertise. I witnessed an audio preservation specialist at the LC's NAVCC artfully use tape to hold down sections of lacquer that had already begun to delaminate from the disc, just so he could try to get one clean transfer attempt with it at his turntable station. Two of the other

---

[14] Jeff Willens, email message to Yuri Shimoda, December 3, 2018.

[15] Melissa Widzinski, email message to Yuri Shimoda, January 4, 2019.

institutions I spoke with also report similar attempts at the mechanical playback of delaminating discs.

"We attempted to retrieve what we could from all of our discs using 'traditional' replay equipment," comments the British Library's Tovell in our January 21, 2019 email correspondence. "We do have several hundred affected by delamination. We attempted to replay these with a turntable if the engineers felt it was safe to do so, using various techniques to keep the lacquer in place (temporary adhesive, playing backwards, playing at half-speed, etc.)."

Audio engineer Willens also details instances where he has had to repair broken discs within NYPL's large collection of glass-based lacquers. One was broken into three pieces, but "I was able to reassemble, play back, and digitize [it] successfully. … Delaminating discs are a different story. Either they're playable, or they're not. You retrieve as much as you can without doing more damage," he shares in an email dated December 4, 2018. "Optical systems … are of course much more preferable than doing a physical playback. ... NYPL will use IRENE at NEDCC on the rare occasions when physical playback would be detrimental to the source."

In our email conversations dated January 4 and 31, 2019, IU's Widzinski describes their policy of not attempting mechanical transfer with cracked and/or delaminating discs: "We store them until an opportunity arises where an optical scan might be feasible. The scope of our project is such that we are still required to optimize throughput and not take significant risks with the materials." Widzinski, like Willens, is referring to the IRENE system, which is an optical solution that is highlighted in the next section. IU sent three broken, glass-based discs from Orson Welles' "The War of the Worlds" broadcast to be scanned by IRENE at the NEDCC. Although these were copies from the originals, they were owned by Welles himself before being

accessioned by IU. "These discs were chosen due to cultural value, since that is one of the most famous radio broadcasts in history," Widzinski continues in her email.

While the preservation reformatting of lacquer discs via mechanical playback is ideal, when it comes to damaged or deteriorating discs, the amount of labor needed to perform a custom, 1:1 (one preservation specialist working with one disc at a time) workflow in order to extract recordings is high. "Getting the 'last, best play' from a fragile recording may require four hours of skilled labor for one hour of sound."[16] Mechanical transfer of 16-inch lacquer discs require special styli, as well as a professional turntable designed to accommodate a large disc and a wide range of playback speeds; this can be quite hard to find due to equipment obsolescence. In addition, mechanical replay does cause deterioration to the shape of the disc's grooves and "because of their susceptibility to deterioration by replay, strategies have to be in place to restrict the replay of mechanical carriers to the absolute minimum."[17] The ultimate cost of losing highly unique material by worsening a break or losing a flake of delaminated lacquer in the mechanical transfer process is a risk all institutions would be unwilling to take.

Solutions: Optical

The IRENE system mentioned by Widzinski and Willens utilizes no-contact digital imaging to optically recover sound recordings from cracked, broken, and delaminating discs. Carl Haber and Vitaliy Fadeyev, two scientists at the Lawrence Berkeley National Laboratory came up with IRENE after hearing the drummer for Grateful Dead talk about the loss of cultural heritage due to the breakdown of recordings on a radio show in 2003. Their experiments resulted

---

[16] Virginia Danielson, "Stating the Obvious: Lessons Learned Attempting Access to Archival Audio Collections," *Folk Heritage Collections in Crisis*, (Washington, D.C.: Council on Library and Information Resources, May 2001), 7.

[17] Schüller and Häfner, 13-14.

in the system that they ended up naming for "Goodnight, Irene" by the Weavers because it was the first record they were able to extract sound from.[18] 'IRENE' has now come to represent: Image, Reconstruct, Erase Noise, Etc. since it creates a high-resolution digital map of a disc by using light, a digital camera, and a laser (to drive the motorized arm that allows the camera to focus properly) to scan images of the disc's groove floor. Then, software analyzes the lateral motion happening within the grooves and converts the data into sound (wav files).

Once LC Digital Conversion Specialist Peter Alyea heard about IRENE, he began to realize its potential for reading damaged discs and forged a collaborative relationship with Haber and the Berkeley Lab. The first 2D IRENE system for reading lateral-cut discs[19] was installed at the LC in 2006 and eventually found its permanent home at the NAVCC (where I became acquainted with its capabilities) when a second 2D/3D system was delivered to the LC for reading vertical-cut discs and cylinders. In 2013, the NEDCC and Berkeley Lab received a grant to further test and develop IRENE "to create a sustainable digital reformatting service for archives, libraries, and museums across the U.S.,"[20] and another system was installed in the Andover, Massachusetts facility. Since then, the NEDCC has used IRENE to help preserve a native Alaskan dialect with the Alaska and Polar Regions Archives at the University of Alaska Fairbanks[21] and historically significant broadcast recordings within the New York Public Radio

---

[18] Mark Hartsell, "Unlocking Sounds of the Past," *loc.gov* (blog), March 12, 2012, https://blogs.loc.gov/loc/2012/03/unlocking-sounds-of-the-past.

[19] When a stylus cuts a groove into the disc in a side-to-side motion it produces a lateral-cut disc.

[20] Northeast Document Conservation Center, "History of the IRENE Project at NEDCC," *nedcc.org*, accessed September 6, 2018, https://www.nedcc.org/audio-preservation/history.

[21] Northeast Document Conservation Center, "The IRENE Technology Helps Preserve a Lost Native Alaskan Dialect, *nedcc.org*, accessed September 6, 2018, https://www.nedcc.org/about/nedcc-stories/attu-audio.

Archives,[22] among other projects. IRENE is ideal for fragile or damaged lacquers since a camera reads the discs' grooves, thus, sparing the audio career from any further wear that could be inflicted by the repeated physical contact of a stylus. This optical playback system is not the only one being explored, though. I became aware of three others at the 2018 Audio Engineering Society (AES) International Conference on Audio Archiving, Preservation & Restoration at the NAVCC.

Stefano Cavaglieri of the Swiss National Sound Archives presented on the VisualAudio system, which takes photos of a disc's surface with an analog camera. The film negatives are digitized at a high resolution so that tracking of the grooves can happen. Cavaglieri emphasizes that ensuring the authenticity of the original recording is the most important part when rerecording for archival purposes: "Some say that imaging is an objective means for transferring the physical representation of a sound recording to another media while retaining full authenticity. I'm tempted as an archivist to jump into this kind of technology because if I trust this sentence, this would be the only way to make an exact copy of an original record."[23] To do so, he attempts to match the specifications of his system to the original recording as much as possible.

Cavaglieri points out that it is not quicker to produce a digital copy with optical photography versus mechanical means, and he acknowledges issues with quantization errors[24] and equalization, specifically in terms of reproducing high frequencies. However, he is quick to

---

[22] Northeast Document Conservation Center, "New Hope for Damaged Media," *nedcc.org* (*IRENE Seeing Sound* blog), June 20, 2014, https://www.nedcc.org/audio-preservation/irene-blog/2014/06/20/damaged-media.

[23] Stefano Cavaglieri, "Expert Transfer Techniques: A Special Focus on Mechanical Discs" (presentation, ARSC Conference, San Antonio, Texas, May 11, 2017).

[24] A quantization error is distortion that occurs when analog sound waves are converted to digital.

note that, unlike mechanical means, VisualAudio can replay broken and delaminated records. "We can take a picture and work on the picture in order to reconstruct the audio. This is the real strength of optical technology. There's room for improvement on the image capture, image processing, and signal processing, [but] imaging is still a good thing."[25] The International Court of Justice (ICJ) in the Hague would agree. Cavaglieri's colleague, University of Fribourg professor Ottar Johnsen and his student Sylvain Stotzer were able to use the VisualAudio method to read fragile, 70-year-old lacquer discs containing recordings of the Nuremberg trials.[26]

Jean-Hugues Chenot of France's Institut National de l'Audiovisuel (INA) has developed the Saphir colored light process to read delaminating and broken discs. Saphir uses the highly reflective properties of a lacquer disc to "highlight subtle changes in the orientation of the groove walls. A standard colour camera is used to collect rings of pictures from the disc. Audio signal is extracted from the collected pictures automatically, under user control."[27] Keeping in mind that INA has around 20,000 cracked lacquer discs and thousands of delaminating discs in its collections, and current scanning time is about three hours for per side of a disc, there are definitely improvements to be made. Sapphir can't be used to read stereo tracks or discs with transparent coating. However, its components are affordable, and imaging has presented good frequency response (up to 20KHz on 78 rpm discs) thus far. Over the past two years Saphir has been used to recover significant recordings within the INA collection, including post-WWII

---

[25] Ibid.

[26] Chris Harland-Dunaway, "This scientist used imaging techniques to rescue sound from the Nuremberg trials," *PRI.org*, accessed February 5, 2019, https://www.pri.org/stories/2019-02-04/scientist-used-imaging-techniques-rescue-sound-nuremberg-trials?fbclid=IwAR3XMTA4_WbfGAOwrxr-AKQTJ9iF87m4WdVFqvm0aGjVfaJnnbezepsACxw.

[27] Jean-Hugues Chenot, Louis Laborelli, and Jean-Étienne Noiré, "Saphir: Optical Playback of Damaged and Delaminated Analogue Audio Disc Records," *Association for Computing Machinery Journal on Computing and Cultural Heritage*, 11 no. 3 (August 2018), pp14, 1.

radio broadcasts and the first-ever recording of fado singer Maria Teresa de Noronha, dated 1939.[28]

Nicholas Bergh of Endpoint Audio Labs in Burbank, California, demonstrated his cylinder transfer machine at the AES Conference in Culpeper. A month later, he returned to deliver a system for the Packard Campus. This machine had the added capability for non-contact playback of cracked and fragile audio cylinders. I was able to take part in the engineers' training on the machine where I learned that Bergh is developing an optical playback system for discs. The original Endpoint Cylinder and Dictabelt Machine includes a laser to adjust the position of the mandrel holding the cylinder to achieve optimal playback by the stylus. In the updated configuration, the laser is used to perform a high-resolution scan of the cylinder. Custom software built-in to a newly added box to the system is able to interpret the scan and create audio output.

The Endpoint optical system for reading discs also employs a laser to create a high-resolution digital surrogate. The system is an add-on to a standard Technics SP-10 turntable, which cost about $1,000 used or $10,000 new. "The main benefit of my optical system is that it is real-time. It takes just as long to play a disc optically as it would to play it with a stylus," says Bergh in an email dated January 11, 2019. "Real-time playback is key for one of the important applications [of optical reading], which is just trying to identify content of a disc." The cost of the basic component of Endpoint's system is notable because the price of optical transfer is higher than mechanical. According to the *Quantifying the Need* survey, the cost to mechanically transfer a standard lacquer disc with no damage is around $75, while the "Specialized Cost per

[28] Chenot et al, 39-40.

Item" is estimated to be $150.[29] This is why institutions, like IU and NYPL, must carefully consider the condition of the disc and the value of its recorded contents into consideration when deciding whether or not to pay the NEDCC for an IRENE scan.

Recommendations

While the NEDCC has demonstrated the most success stories with the IRENE system, the price to transfer is too high for many institutions to pay unless they have been awarded a grant, which would account for additional time and labor from its employees. The components of the Saphir and VisualAudio systems are affordable for a wider range of institutions, but require the expertise of highly trained audio or electrical engineers. The Endpoint system is very affordable, making it a strong candidate as the most viable optical method for all institutions.

The need to recognize highly at-risk materials like lacquer discs in their collections is an essential skill for an archivist. Expanding existing library, archival, and information science curricula to strengthen students' training in the area of recorded sound, the composition of sound carriers, and techniques for reformatting analog formats to digital is key. Continuing to stay abreast of existing and emerging reformatting technologies, as well as funding sources to help finance preservation, is just as integral. Indiana University Bloomington professor and Media Preservation Specialist for MDPI Patrick Feaster has been working on software to process the TIFF files produced by the IRENE system with the hopes that users would be able to access the visual preservation masters. Studies such as his should be followed closely by any repository with damaged discs in its collections.

---

[29] Lyons et al, 18.

Bibliography

Bamberger, Rob and Sam Brylawski on behalf of the National Recording Preservation Board. *The State of Recorded Sound Preservation in the United States: A National Legacy at Risk in the Digital Age* (Washington, DC: Council on Library and Information Resources and the Library of Congress, 2010).

Behl, Harrison. "Audio Formats: Characteristics and Deterioration." In *ARSC Guide to Audio Preservation*, edited by Sam Brylawski, et al. Eugene: Association for Recorded Sound Collections; Washington, D.C.: Council on Library and Information Resources and the Library of Congress, 2015.

Burke, Brandon. "Designing a Housing for the Horizontal Storage of Cracked or Broken Phonograph Discs." *ARSC Journal* 25, no. 1 (Spring 2018): 28-40.

Calvi, Elise. "Floating Disks." *E. Lingle Craig Preservation Lab Blog.* March 9, 2016. https://blogs.libraries.indiana.edu/craiglab/2016/03/09/floating-disks/.

Cavaglieri, Stefano. "Expert Transfer Techniques: A Special Focus on Mechanical Discs." Presented at ARSC Conference, San Antonio, Texas, May 11, 2017.

Chenot, Jean-Hugues, Louis Laborelli, and Jean-Étienne Noiré. "Saphir: Optical Playback of Damaged and Delaminated Analogue Audio Disc Records." *Association for Computing Machinery Journal on Computing and Cultural Heritage*, 11 no. 3 (August 2018): pp 14, 1-29.

Danielson, Virginia. "Stating the Obvious: Lessons Learned Attempting Access to Archival Audio Collections." *Folk Heritage Collections in Crisis*. Washington, D.C.: Council on Library and Information Resources, May 2001.

Harland-Dunaway, Chris. "This Scientist used imaging techniques to rescue sound from the Nuremberg trials." *PRI.org.* Accessed February 5, 2019.https://www.pri.org/stories/2019-02-04/scientist-used-imaging-techniques-rescue-sound-nuremberg-trials?fbclid=IwAR3XMTA4_WbfGAOwrxr-AKQTJ9iF87m4WdVFqvm0aGjVfaJnnbezepsACxw.

Hartsell, Mark. "Unlocking Sounds of the Past." *loc.gov* (blog), March 12, 2012. https://blogs.loc.gov/loc/2012/03/unlocking-sounds-of-the-past.

Lyons, Bertram, Rebecca Chandler, and Chris Lacinak. *Quantifying the Need: A Survey of Existing Sound Recordings in Collections in the United States*. Brooklyn, NY: AVPreserve, 2014.

National Archives & Record Administration. “Format Guide to Sound Recordings.” October 2014, accessed January 31, 2019. https://www.archives.gov/files/preservation/formats/pdf/format-guide-to-sound-recordings.pdf.

Northeast Document Conservation Center. “History of the IRENE Project at NEDCC.” *nedcc.org*, accessed September 6, 2018. https://www.nedcc.org/audio-preservation/history.

Northeast Document Conservation Center. “The IRENE Technology Helps Preserve a Lost Native Alaskan Dialect." *nedcc.org*, accessed September 6, 2018. https://www.nedcc.org/about/nedcc-stories/attu-audio.

Northeast Document Conservation Center. “New Hope for Damaged Media.” *nedcc.org* (*IRENE Seeing Sound* blog), June 20, 2014. https://www.nedcc.org/audio-preservation/irene-blog/2014/06/20/damaged-media.

Pymm, Bob. “Preservation of Audiovisual Media: Traditional to Interactive Formats.” In *Preservation Management for Libraries, Archives and Museums,* edited by G.E. Gorman and Sydney J. Shep. London: Facet Publishing, 2006.

Schüller, Dietrich and Albrecht Häfner, eds. *Handling and Storage of Audio and Video Carriers (IASA-TC 05)*. London: International Association of Sound and Audiovisual Archives, 2014.

Sueiro Bal, Marcos and Jeff Willens. “Survey of Suggested Treatments for Removing Acidic Exudation from Vintage Lacquer Discs.” Poster presented at Audio Engineering Society International Conference on Audio Archiving, Preservation & Restoration, Culpeper, Virginia, June 28-30, 2018.