NATIONAL ENDOWMENT FOR THE
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DIVISION OF PRESERVATION AND ACCESS

Narrative Section of a Successful Application

The attached document contains the grant narrative of a previously funded grant application. It is not intended to serve as a model, but to give you a sense of how a successful application may be crafted. Every successful application is different, and each applicant is urged to prepare a proposal that reflects its unique project and aspirations. Prospective applicants should consult the NEH Division of Preservation and Access application guidelines at http://www.neh.gov/divisions/preservation for instructions. Applicants are also strongly encouraged to consult with the NEH Division of Preservation and Access staff well before a grant deadline.

Note: The attachment only contains the grant narrative, not the entire funded application. In addition, certain portions may have been redacted to protect the privacy interests of an individual and/or to protect confidential commercial and financial information and/or to protect copyrighted materials.

Project Title: Investigation of Cellulose Nitrate Motion Picture Film Chemical Decomposition & Association Fire Risk

Institution: University of Wisconsin, Madison

Project Director: Vance L. Kepley

Grant Program: Research and Development

Significance

When it comes to nitrate film, our cultural heritage is inextricably linked to issues of human safety. Cellulose nitrate was used as the base for professional motion picture film for the first half of the 20th century, which means that virtually all works of commercial cinema made between the 1890s and the early 1950s were originally shot on nitrate stock. However, nitrate film is a highly flammable material. A relative of guncotton, cellulose nitrate ignites readily, burns at elevated temperatures, and cannot be easily extinguished. Nitrate fires generate their own oxygen supply, continuing to blaze even if completely immersed underwater. As they burn, nitrate fires also produce toxic gases, thus amplifying the damage they can wreak.

Nevertheless, cellulose nitrate was very common during the early 20th century, and not only in cinemas. It was used to make a variety of plastic objects (*e.g.*, combs and children's toys) and also served as the base material for many still photographic negatives. Moving image film has always been recognized to present an especially elevated risk, because it is more heavily nitrated than other nitrocellulose-containing products and because it is stored in tightly wound rolls of 1,000 feet or more. The sheer length of motion picture reels ensured a massive inferno if even a single roll went up.

Sadly, nitrate film has taken an elevated toll in both human and material terms. In non-commercial archives alone, "nitrate fires have taken at least five lives and destroyed literally millions of feet of our cinematic heritage," including "'all the films that had been produced by both camps during the [Spanish] Civil War'; at least fifty unique actuality films documenting Czech life in the interwar period; nearly all of the pre-1951 holdings of one of Egypt's major film studios; more than 12.5 million feet of unique Universal [studio] outtakes; 'irreplaceable material' held in Canada's National Film Board Archives; all but three of early master Victor Sjöström's silent Swedish works; and an unknown number of unique titles held by the Cinematheque Française."[1] Nitrate fires have thus taken unique heritage materials that document not only the mass media of cinema, but also the major historical events and the more quotidian moments of the first half of the 20th century. Anecdotal accounts attest to other victims of nitrate fires: manuscripts and museum materials that were caught in the flames, or damaged indirectly by sprinkler systems.

Like all cellulose nitrate products, nitrate film readily decomposes under ambient conditions. Almost inevitably, the complicated chemical structure of cellulose nitrate starts to break down in a seemingly autocatalytic reaction. Nitrate decomposition has almost certainly claimed more unique materials than nitrate fires, but it is sometimes difficult to separate the two factors, since chemical decomposition increases fire risk. As cellulose nitrate decays, its autoignition temperature—the temperature at which it will spontaneously ignite—drops dramatically. Recorded temperatures as low as 41.1 °C (106ºF) have spontaneously ignited nitrate roll film,[2] and it is possible that the autoignition temperatures may dip even lower in uncontrolled settings.

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[1] Heather Heckman, "Burn After Viewing, or, Fire in the Vaults: Nitrate Decomposition and Combustibility," *The American Archivist* 73 (Fall/Winter 2010): 484.
[2] James W. Cummings, Alvin C. Hutton, and Howard Silfin, "Spontaneous Ignition of Decomposing Cellulose Nitrate Film," *Journal of the Society of Motion Picture and Television Engineers* 54 (March 1950): 269-270.

In the 1970s and 1980s, the combined persuasive force of the threats to both human safety and image stability culminated in the "Nitrate Won't Wait" campaign, a large-scale effort to migrate all flammable film to "nonflam," safety stock. Unfortunately, "nonflam" meant cellulose acetate. Cellulose acetate-base film poses less of a fire risk; however, it decays even more readily than nitrate-base film. In the early 2000s, scientists at the Image Permanence Institute (IPI) estimated that the average lifespan of cellulose acetate film was consistently a very low 40 years.[3] Although the IPI found a great degree of variation among nitrate samples, some of the tested nitrate was determined to be more stable than the tested triacetate, with predicted lifespans ranging from 50 to 600 years.[4] And even before the IPI findings were disseminated, the "Nitrate Won't Wait" idea was being undermined by its own urgency. Film processing labs had only recently gotten into the business of preservation copying, and they were rushed to produce acetate duplicates of nitrate originals. Too often, the results were of inferior quality. What's more, preservation copying is both costly and labor-intensive, rendering it an inefficient means of preserving large volumes of material. In so far as the nitrate problem was one of image preservation, copying proved to be a poor solution.

A better understanding of the risks and elevated costs associated with migration led many moving image archivists to abandon the central thrust of the "Nitrate Won't Wait" movement. Most major American film archives disavowed copy-and-destroy policies, seeking instead to preserve nitrate films over the long term in temperature- and humidity-controlled vaults. Many smaller institutions were never able to afford nitrate copying in the first place, thereby defaulting to the same long-term preservation strategy. Of course, this continued presence of a hazardous material in film collections translates into substantial expenses as well. It is costly to purchase NFPA-compliant storage cabinets and vaults, so costly that many smaller institutions never do. But because of its hazardous material (HAZMAT) designation, nitrate film is difficult to ship or to dispose of safely. The problems of transportation and disposal are so acute that a National Park Service *Conserve O Gram* prompts government employees to exploit a loophole allowing unregulated transport of nitrate film by government workers in government vehicles. The *Conserve O Gram* cautions, however, that the driver should neither leave the car parked in the sun too long, nor run its heater "excessively."[5]

To make matters worse, there are gaping discrepancies in the standard sources describing nitrate decomposition and combustibility. The 1950 Cummings *et al.* study establishing 41.1ºC as a sufficiently elevated temperature to ignite decomposed roll film also put forward the idea that nitrate decomposition is a five-step process:

> [I]n the first stage of deterioration the photographic portion usually shows an amber discoloration with fading of the picture image. In the second stage, the emulsion becomes adhesive and the film convolutions tend to stick together during unrolling. Rolls of third-stage film have annular portions which are soft, contain gas bubbles, and emit a noxious odor easily recognizable. In the fourth stage of deterioration, the entire film is soft, its

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[3] P. Z. Adelstein, J. M. Reilly, and F. G. Emmings, "Stability of Photographic Film: Part VI, Long-term Aging Studies," *SMPTE Journal* 111, no. 4 (April 2002): 142-143.
[4] P. Z. Adelstein et al., "Stability of Cellulose Ester Base Photographic Film: Part IV--Behavior of Nitrate Base Film," *SMPTE Journal* 104 (June 1995): 369.
[5] National Park Service, "Handling and Shipping Cellulose Nitrate Film," *Conserve O Gram*, June 2003, 1.

> convolutions welded into a single mass and frequently its surface is covered with a viscous froth. A strong noxious odor is given off, unmistakable to inspection personnel when once identified. In the fifth and final stage, the film mass degenerates partially or entirely into a brownish acrid powder.[6]

Cummings and his colleagues linked lowered ignition thresholds to decomposition, attesting that the first roll to ignite was in "an advanced stage of deterioration," and that no film "in good condition has self-ignited."[7] Implicitly, the study seemed to argue that ignition thresholds continue to drop as decomposition advances, a generally upheld view in contemporary sources on nitrate decomposition (most of which also reproduce a version of the Cummings *et al*. five-stage process[8]).

The Kodak material safety data sheet (MSDS) for nitrate roll film, however, suggests that the relationship between decay and ignition threshold is exponential rather than arithmetic. According to the MSDS, the final, brown powder stage is "shock sensitive"—that is, prone to combust at either low temperatures or on impact.[9] The International Standard, *ISO 10356—Cinematography—Storage and Handling of Nitrate Motion Picture Films*, meanwhile, contends just the opposite, stating that nitrate fire risk drops in the final stages of decay: "By the time the film reaches category e) [stage 5] it has lost virtually all of its nitrate groups, and its flammability has then been reduced to approximately that of the cellulose itself, i.e. comparable to the flammability of paper."[10] Complicating the issue still further, a 1990 paper on nitrate decay found that the brown powder contained both nitrogen and oxygen. The authors hypothesized that the substance was produced in a reaction between nitrate-base film and metal storage cans containing iron,[11] suggesting, perhaps, that there might be multiple brown powder substances with different chemical compositions, or that brown powder might not be the final stage of all cellulose nitrate decomposition reactions.

Can temperatures below the recognized 41ºC threshold start nitrate burning? Does the autoignition temperature continue to drop as film decays? Is the fire risk posed by the brown powder akin to that posed by gunpowder or to that posed by a standard manuscripts collection? Could the formation of the brown powder be prevented entirely by storage in iron-free cans? The answers are not at all clear. Very little published research on cellulose nitrate motion picture decay has appeared in the past decade, and few of the recommendations advanced in the early 1990s have been tested or implemented.

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[6] Cummings, Hutton, and Silfin, "Spontaneous Ignition of Decomposing Cellulose Nitrate Film," 271-272.
[7] Ibid., 269-270.
[8] See, for example, *The Film Preservation Guide: The Basics for Archives, Libraries, and Museums* (San Francisco: National Film Preservation Foundation, 2004), 16; "Kodak Cellulose Nitrate Film (discontinued 1952) Material Safety Data Sheet" (Eastman Kodak Company, 2003), 1; *ISO 10356--Cinematography--Storage and Handling of Nitrate-Base Motion-Picture Films*, 1st ed. (Geneva: International Organization for Standardization, 1996), Annex B; "Handling, Storage and Transport of Cellulose Nitrate Film" (International Federation of Film Archives, 1991), 9; Eileen Bowser and John Kuiper, *A Handbook for Film Archives* (New York: Garland, 1991), 18-19; Jean-Louis Bigourdan, "From the Nitrate Experience to New Preservation Strategies," in *This Film is Dangerous: A Celebration of Nitrate Film*, ed. Roger Smither and Catherine A. Surowiec (Brussels: FIAF, 2002), 53.
[9] "Kodak Cellulose Nitrate Film (discontinued 1952) Material Safety Data Sheet," 1.
[10] *ISO 10356--Cinematography--Storage and Handling of Nitrate-Base Motion-Picture Films*, Annex B.
[11] M. Edge et al., "Mechanisms of Deterioration in Cellulose Nitrate Base Archival Cinematographic Film," *European Polymer Journal* 26, no. 6 (1990): 629-630.

Worse, virtually no English-language published research on the fire risk posed by cellulose nitrate picture decay has appeared in the last half-century. With the notable exception of a Canadian Explosives Research Laboratory investigation into cold storage explosive venting,[12] widely disseminated investigations into nitrate fire safety ended with the arrival of triacetate film, coincident with the publication by Cummings *et al.* In the meantime, heritage nitrate films in collections around the world have continued to age. The oldest possible film Cummings *et al*. could have tested would have been roughly 55 years old (and it is unlikely any of their test material dated to the 1890s); today, the youngest possible film in archival nitrate holdings is at least 60 years old (and some of the most valuable are considerably older).

There are several reasons for the paucity of physical data about nitrate motion picture film. First and foremost, nitrate film is a discontinued product. Chemical manufacturers such as Kodak and DuPont eliminated their risk associated with this product by ceasing its production. Nitrate is no longer used in the contemporary film industry, in either production or exhibition. From the 1890s to the 1950s, the fire risks associated with nitrate put audiences at risk; today, nitrate films pose a much greater threat to cultural objects than to human beings.

Second, there are intellectual barriers between the archival, safety, and chemical communities. To archivists, "cellulose nitrate decomposition" means slow chemical breakdown in ambient conditions; to safety engineers, the first meaning of the same phrase is almost certainly rapid chemical breakdown during a fire. The technical language spoken by chemists presents an even greater hurdle for many archivists, few of whom have strong backgrounds in the hard sciences. Most archivists would be uncomfortable extrapolating best practices from existing scientific research or initiating fruitful collaborations for new scientific research.

There are also communication barriers between archival institutions. While nitrate motion picture film has its own folklore in the profession, very few archivists are charged with caring exclusively for nitrate film. Between the recognized liabilities associated with nitrate film, and the conflicting information surrounding it, non-specialists experience justifiable anxiety about nitrate. Meanwhile, investigations into nitrate fires and fire risk are often kept internal. Results are diffused through a grapevine that may amplify uncertainty, especially for smaller institutions.

Finally, and probably most importantly, samples for nitrate chemical safety research are rarely available. Safety research means destructive testing, a clear violation of basic principles of moving image stewardship. The inevitable loss of quality due to nitrate decay on the one hand, and analog migration on the other, means that all nitrate materials are treated as unique—and of course, many also literally are.

The fact that nitrate film is no longer made is inescapable. The tendency for film archivists to get humanities, rather than rigorous scientific, training is unavoidable in at least the medium-term. However, projects like this one—that aim to produce widely disseminated, fully transparent results that can be readily understood by non-technical audiences—may ameliorate communication barriers in the short-term. Most importantly, this project presents an exceptional

[12] Greg Hill, "New Nitrate Film Storage for Library and Archives Canada," *Topics in Photographic Preservation* 10 (2003): 74-85.

opportunity, because it has already secured a sample of heritage nitrate roll films in varying states of decay and from varying original sources. In a field in which small sample sizes have represented an impediment to a complete understanding of the inherent instabilities and ideal means of preservation of nitrate films, we cannot pass up opportunities to generate more data.

The film medium was also a nitrate medium for a long time—from the dawn of cinema, through the First and Second World Wars, the Roaring Twenties, and the Great Depression, right up to the atomic age and the collapse of the Hollywood Studio System. The imperative to preserve this rich corpus of moving images is now to store them for the foreseeable long-term. However, we are still struggling to properly evaluate the related dangers of fire risk and decay in order to safely handle and store nitrate film collections. It is therefore vitally important that we seize this chance to enrich our empirical understanding of nitrate film decomposition, rather than continuing to rely on anecdotal wisdom.

Although motion picture nitrate film presents a unique set of preservation challenges, greater knowledge about its decay and flammability characteristics will enhance our understanding of other nitrate materials, as well. Still photographic film is considered somewhat less of a risk, because it is usually stored in flat sheets, rather than in rolls. According to Douglas Nishimura of the IPI, it has also been demonstrated to burn less readily in laboratory settings.[13] But it shares much in common chemically with motion picture film, and it is now regulated under the same NFPA standard. Changes in the way we assess the risk posed by motion picture nitrate collections could very well impact stewardship of still photograph nitrate collections. Conservators who work with cellulose nitrate objects, meanwhile, will find methodological and theoretical value in our project, even if the precise results cannot be generalized to the collections in their care.

If funded, this project will not only produce valuable data, it will also serve as a model for continuing collaboration between archivists, conservators, and chemists. It will further our understanding of both the fire risk posed by heritage nitrate motion picture film and the underlying chemistry governing cellulose nitrate decomposition. It will generate improved best practice guidelines for the safe handling and long-term storage of nitrate film, culminating in the publication of a white paper and the submission of proposed amendments to update and unify *NFPA 40, Standard for the Storage and Handling of Cellulose Nitrate Film* and *ISO 10356—Cinematography—Storage and handling of nitrate-base motion picture films*. It will arm institutions with better information for benefit-cost analyses about cellulose nitrate holdings, and will help to eliminate contradictory information circulating in current standards.

Background of Applicant

The Wisconsin Center for Film & Theater Research and the Mahanthappa Research Group in the Chemistry Department of the University of Wisconsin-Madison are sponsoring the project, under the supervision of Vance Kepley (Professor of Communication Arts, Director of the Wisconsin Center for Film & Theater Research) and Mahesh Mahanthappa (Assistant Professor of Chemistry). The Wisconsin Center for Film & Theater Research and the Mahanthappa Lab have

[13] D Nishimura to Heather Heckman, "RE: NEH Grant Advisory Board", April 11, 2011.

also partnered with the Wisconsin Historical Society, which will donate films and the expertise of Preservation Coordinator Kathleen Mullen.

Project Co-Sponsors

The Wisconsin Center for Film & Theater Research (WCFTR) houses one of the oldest and most extensive collections of print, audio-visual, and graphic materials relating to film, theater, radio and television in the United States. The WCFTR is administered by the Communication Arts (Comm Arts) Department of the University of Wisconsin-Madison (UW) and works in close cooperation with the Wisconsin Historical Society (WHS). It is an associate member of the International Federation of Film Archives (FIAF).

As arguably the first American archive to actively collect not just the works, but also the records, produced by the mass media industry, the WCFTR is home to diverse materials related to film, theater, and broadcasting. WCFTR collections include fifteen thousand motion pictures, television shows and videotapes; two million still photographs and promotional graphics; several thousand sound recordings; the corporate records of the National Broadcasting Company (NBC) and United Artists (UA); and more than three hundred personal manuscripts collections. Holdings focus on US entertainment-based media, though it also has smaller collections in social action documentary and non-US film, notably Hong Kong, Taiwanese and Soviet cinema.

Since its founding in 1960, the WCFTR has cared for a small, but significant, collection of nitrate films. The WCFTR's nitrate collection dates from the 1910s to the late 1940s, and includes unique silent fragments, World War II public service announcements, shorts from the Hal Roach studio, early 35mm sponsored films, and Ed Sullivan's "Famous First." In addition, the WCFTR curates a second small, but significant, cache of nitrate film: amateur and state-produced 35mm footage owned by the Wisconsin Historical Society.

The mid-range status of the WCFTR when it comes to nitrate collecting has placed it between major American film archives, like the Library of Congress and the George Eastman House, on the one hand, and non-film specialized institutions, like other state historical societies, on the other. This awkward position has made the WCFTR especially sensitive to the "nitrate problem." Historically too small to afford massive investment in fully-compliant vaults, yet too large to continue to risk storage without them, the WCFTR has a particularly strong interest in generating better information for risk analysis. And because it has some understanding of the different challenges posed to large and small nitrate collecting institutions, it is uniquely positioned to confront the issues of nitrate decay and flammability from the archival perspective.

Perhaps most importantly, the WCFTR is an initiative of the UW Comm Arts Department, which means it is associated not just with an acclaimed Film Studies program, known particularly for its historical approach to cinema, but also with one of the world's preeminent research universities. Among American public universities, UW ranks 2nd in overall research expenditures, 4th in federally funded research, and 2nd in non-federally funded research. It is home to more than 2,000 faculty members, who together have won more prestigious awards and grants than the faculty of any other US public university.

The UW Chemistry Department is held in particularly high regard. Consistently ranked among the best American chemistry programs (public or private), the UW Chemistry Department gives graduate degrees in materials, analytical, organic, and physical chemistry. It maintains world-class core facilities for chemical characterization; those most relevant to this project are nuclear magnetic resonance spectroscopy, mass spectrometry, infrared spectroscopy, polymeric materials characterization, size-exclusion chromatography, tensile testing, and electron microscopy. Sponsorship from the UW Chemistry Department ensures equipment and expertise of the highest caliber, established relationships with analytical services providers, and sound chemical and analytical methodologies for understanding the "Nitrate Problem."

The Mahanthappa Research Group specializes in soft materials science, specifically, and the synthesis and physical characterization of new polymeric materials. The Group has two complementary skill sets: the ability to develop and to exploit new synthetic methods to produce new molecular structures with precise control over structure, functional group placement, and monomer sequence; and the ability to physically characterize materials as ensembles of molecules to effectively evaluate their morphology, properties, and ultimate utility in applications. In other words, the Mahanthappa Group is capable of synthesizing and completely characterizing complex polymers, both chemically and as bulk materials.

The Mahanthappa Group has access to facilities for infrared spectroscopy, mass spectrometry, ^{1}H nuclear magnetic resonance, pH measurement, differential scanning calorimetry (DSC), intrinsic viscosity tests, and thermogravimetric analysis (TGA) (see also *Appendix A*: *Facilities Statement*). With paid services of the UW Chemistry Department Machine Shop, they can easily assemble the environmental chambers necessary for the accelerated aging tests proposed below. Therefore, the great majority of the experimental methods required for the project will be conducted on site under the careful supervision of qualified project staff.

Project Partners

The Wisconsin Historical Society (WHS) is both a state agency and a private membership organization. Founded in 1846, two years before statehood, and chartered in 1853, it is the oldest American historical society to receive continuous public funding. By statute, it is charged with collecting, advancing, and disseminating knowledge of Wisconsin and of the trans-Allegheny West. The Library–Archives division supports the mission of the Historical Society by acquiring, preserving, and providing access to an immense collection of published and unpublished material documenting the history of North America, second only to the Library of Congress. The Archives provide access to collections of unpublished materials about the history of Wisconsin and a wide array of topics related to North American history. These collections include letters, diaries, organization records, state and local government records, oral histories—and, of course, photographs and films in all sizes and formats, from glass plate to paper, and from nitrate to polyester.

The WHS cooperated with the Department of Communication Arts (at that time, the Department of Speech and Theater) to form the Wisconsin Center for Film and Theater Research. In a long-standing agreement, the WCFTR has been charged with curating and providing access to WHS motion picture collections, while the WHS has been charged with curating and providing access to WCFTR manuscripts collections. The WHS provides storage space for the collections, offices for the WCFTR's archivists, and access to WCFTR collections through the Archives Research Room on the 4th floor of the historic Wisconsin Historical Society building. The WHS also provides conservation services for the WCFTR. WHS conservators repair damaged items owned by the WCFTR, and consult with WCFTR staff about long-term storage facilities and equipment.

History, Scope, and Duration

This project was born when Heather Heckman, a Ph.D. student in the University of Wisconsin's Department of Communication Arts and an Archives Assistant at the WCFTR and the WHS, attended a Nitrate Film Committee meeting at the 2008 Association of Moving Image Archivists (AMIA) conference. She agreed to undertake a research project for the Committee, checking the footnotes used in manuals and standards on nitrate handling. The Committee was particularly concerned with the description of the brown powder as "shock sensitive" in the Kodak MSDS. From their own anecdotal experience, they felt strongly that the powder did not combust on impact, and found that the phrase, "shock sensitive," significantly increased the difficulty of shipping nitrate materials.

Heckman published her results in the Fall/Winter 2010 issue of the *American Archivist.* Using the citation tracking methodology, she was unable to find sound evidence that the brown powder either was or was not shock sensitive. Instead, Heckman argued that the risk posed by heritage nitrate films could not be reliably established from the literature she reviewed, and noted that empirical work on nitrate film decay published in hard science journals was rarely cited in archival or safety sources. In the end, she was only able to conclude, "the dialogue among the archival, safety, and scientific communities is inadequate and … no community has satisfactorily established the evolution of flammability as nitrate decomposes."[14] At the end of her piece, she called for increased collaboration between practicing archivists and chemists, including the donation of research samples, and for the publication of "updated white papers on nitrate conservation."[15] She continues to collect citations about nitrate motion picture film, expanding the bibliography she initially generated for her research paper (see *Appendix H: Preliminary Bibliography*).

That same fall, the WCFTR and the WHS began to re-appraise their nitrate holdings. Their staff found anecdotal support for the Edge *et al.* claim that brown powder forms when iron is present. Films stored in plastic cans, or wound on flimsy metal (presumably aluminum) reels did not seem to have decomposed into brown powder. Films wound onto heavy metal reels (presumably steel) tended to be in the worst condition, often with large deposits of brown powder along the film edge where it was in direct contact with the metal. External deposits did not necessarily correlate with poor image quality once the film was unwound, as a five-stage model culminating with the brown powder might seem to suggest.

A first round of review and deaccessioning took place in the fall of 2010. During a second round, in the spring of 2011, conservation staff at the WHS and the WCFTR agreed to donate deaccessioned films to science, rather than to immediately dispose of them. Conservation staff

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[14] Heckman, "Burn After Viewing," 486.
[15] Ibid., 505.

also saved brown powder that was cleaned from the films during the reappraisal project. All of the spring 2011 material slated for deaccessioning and disposal was returned to WHS freezers, so that it might be used for research purposes. The WHS Appraisal Committee has approved all deaccessioning candidates, independent of the proposed research project.

However, the WHS and the WCFTR share an active plan to relocate their nitrate holdings to a more secure location over the course of the next two years. Access copies of their most valuable nitrate works will be made, and then all their combined nitrate holdings will be placed on deposit in compliant vaults. At the end of this two-year period, all deaccessioned films still in the WHS freezers will be safely destroyed. The window of opportunity for this research project is therefore very brief.

This project has not been previously supported by the NEH, and the research team anticipates that a three-year study period should shed sufficient chemical insight into the safety issues involved in nitrate storage and handling per the *Work Plan* and *Dissemination* sections below.

Methodology and Standards

This project investigates the veracity of the following theoretical model of cellulose nitrate film decomposition, proposed by Louvet *et al.* in 1995: Cellulose nitrate film decomposition initially attacks the nitrate groups added to cellulose in the nitration process. Nitrogen-oxygen bonds in the nitrate groups are readily cleaved by even slightly elevated temperature and humidity levels, in a reaction that initially releases nitrogen dioxide (NO_2). In turn, NO_2 reacts with moisture in a series of steps to form nitric oxide (NO), which attacks the original cellulose nitrate material, breaking more hydrogen-oxygen bonds in an autocatalytic, secondary decomposition reaction. NO further reacts with the silver in the emulsion, bleaching and fading the image.[16]

The project also investigates Edge *et al.*'s 1990 hypotheses about the role of iron in cellulose nitrate decomposition: Iron attacks the bonds in the molecule's cellulosic backbone. Iron reacts with the nitrogen byproducts of the primary decomposition reaction, generating basic compounds that attack the nitrogen-oxygen bonds of nitrate groups in another autocatalytic reaction. Iron-catalyzed reactions lead to the production of a highly basic brown powder substance, consisting "largely of NO … with the presence of moisture," and some iron.[17]

However, since the primary goal of this project is to generate practice-centered results, we particularly focus on the confirmation or refutation of the following five practical hypotheses:

- Visual classification into the "five stages" of nitrate decay correlates with relative measured severity of decay.
- Heritage nitrate film burns equally as readily and as intensely as newly manufactured nitrate film did.
- Nitrate film's autoignition temperature declines steadily as nitrate film decays.

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[16] A. Louvet, B. Lavadrine, and F. Flieder, "Size Exclusion Chromatography and Mass Spectrometry of Photographic Bases in Cellulose Nitrate Degradation," *The Journal of Photographic Science* 43 (1995): 30-35.
[17] Edge et al., "Mechanisms of Deterioration," 628.

- Re-housing nitrate films in iron-free storage containers arrests the production of the brown powder substance.
- The brown powder substance is shock-sensitive.

Standard experimental and analytical methods will be used to test all of our hypotheses, and standard statistical methods will be used to analyze all of our results.

Samples will be drawn from heritage nitrate film donated to the project. The WCFTR will provide portions of 5 silent compilation reels in very poor condition. Fragments that could be unwound from the reels have been re-housed and will remain in the WCFTR's collections; the remaining film, fused into a sticky mass at the center of the reel, will be given to the project. Brown powder samples from each of these reels have also been collected for the project. The WHS will donate at least 7 rolls of nitrate footage in varying physical conditions. As of March 2011, 4 of the WHS rolls (3 of which were reels of the same film) were in good condition, showing no visible signs of decay. 3 rolls were in poorer condition, suffering partially from emulsion bleaching, base stickiness, and blistering. None of the WHS rolls had fused into a single mass. Samples of the brown powder were also collected from the WHS holdings. The WCFTR and WHS donations alone give the project a minimum of 11 films and 5 brown powder deposits from which to collect experimental samples. This sample size is small, but it compares favorably to previous investigations of nitrate decay, which had access to only 4[18] or 5 films.[19] If this project is funded, we will also solicit additional donations of film material. The Indiana State Archives has already given 1 roll of film in poor condition and an associated brown powder sample to the project.

To evaluate the efficacy of the five-stage model of decay, we will rate the decay of all samples following the inspection method used in the field along with four separate quantitative methods. All of our samples will be classified independently by at least three trained archivists according to the simplified five-stage model published in *The Film Preservation Guide*:

1. Image fading. Brownish discoloration of emulsion. Faint noxious odor.
2. Sticky emulsion. Faint noxious odor.
3. Emulsion softens and blisters with gas bubbles. More pungent odor.
4. Film congeals into a solid mass. Strong noxious odor.
5. Film disintegrates into brownish powder.[20]

Films showing no signs of decay will be rated 0. Then, following Derrick *et al.*,[21] we will use both elemental analysis to measure the carbon, hydrogen, and nitrogen contents of each sample *and* infrared spectroscopy to look for signs of decay, including the accumulation of salts, and the depletion of plasticizing agents like camphor. We will also test the acidity of all our samples,

[18] Ibid., 634.
[19] Adelstein et al., "Stability of Cellulose Ester Base Photographic Film: Part IV--Behavior of Nitrate Base Film," 359.
[20] *The Film Preservation Guide*, 16.
[21] Michele Derrick, Vinod Daniel, and Andrew Parker, "Evaluation of Storage and Display Conditions for Cellulose Nitrate Objects," in *Preventive Conservation: Practice, Theory and Research. Preprints of the Contributions to the Ottawa Congress, 12-16 September 1994* (International Institute for Conservation of Historic and Artistic Works, 1994), 207-211.

following the method endorsed by the Image Permanence Institute (IPI). With the possible exception of the brown powder, nitrate decomposition produces very acidic compounds. Acidity tests have therefore been shown to measure degradation accurately and quickly before other standard tests (e.g., tensile properties, wet emulsion strength, visual inspection). The IPI particularly recommends the water-leach method for its high levels of precision and reproducibility.[22] In the water-leach test for nitrate film, a 1-gram sample is submerged in 38ºC water for 24 hours. During this time, the acid leaves (or leaches from) the film sample. After leaching, the film is removed and the pH level of the water is measured. Finally, we will test the intrinsic viscosity of the samples. Results from all four measures will be compared to the visual classifications in an effort to quantify the efficacy of the five-stage model already in use in the field.

To determine the flammability of our heritage nitrate samples, we will analyze them by differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA). Specimens collected from each of the films and from the brown powder deposits will be analyzed by DSC to assess any thermal transitions (melting or decomposition temperatures) under an inert atmosphere (typically, nitrogen). TGA analysis involves heating samples under ambient conditions to assess their decomposition under air. Both DSC and TGA analyses employ very small samples (~ 3-5 mg), rendering them low-risk methods for quantifying hazards such as rapid combustion or explosive detonation. The DSC and TGA results will be compared to the hazard ratings given in the Kodak MSDS and other safety sources.

Autoignition temperatures for the samples tested can be derived from the DSC and TGA analyses. Therefore, this same set of tests will help us to correlate autoignition temperature and level of decay. All DSC/TGA samples will also be tested for decomposition using the visual classification, elemental analysis, infrared spectroscopy, pH and intrinsic viscosity methods described above. We will seek correlations between the autoignition temperature and decomposition rate data sets.

To test the hypotheses by Edge *et al.* regarding the formation of the brown powder, and to determine whether re-housing nitrate films in metal-free containers will arrest its formation, we will adapt the methodology developed by Derrick *et al*. for accelerated aging of nitrate stocks.[23] We will start by collecting film can samples, including Department of Transportation approved metal cans, heritage cans with significant iron content, and plastic cans. The composition of the cans will be analyzed with spectroscopy. Next we will collect small specimens from each of our sample films. Residual powder will be wiped from all specimens, which will be divided into vials lined with can samples. A control group will be placed into unmodified vials.

The vials will be divided into four environmental chambers. The first chamber will replicate standard freezer conditions (-20ºC); the second chamber will replicate ISO recommendations for nitrate film storage, with cold temperatures and low relative humidity (4ºC; 30-50% RH); the third chamber will accelerate aging with elevated temperatures (50ºC; 30-50% RH); and, the fourth chamber will accelerate aging with elevated temperatures and high humidity (50ºC; 80-

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[22] P. Z. Adelstein et al., "Stability of Cellulose Ester Base Photographic Film: Part III, Measurement of Film Degradation," *SMPTE Journal* 104, no. 5 (1995): 281–291.
[23] Derrick, Daniel, and Parker, "Evaluation of Storage and Display Conditions for Cellulose Nitrate Objects."

90% RH). Like Derrick *et al*., we are using relatively low temperatures; however, we will extend the trial considerably longer, from 75 days to 360 days (or approximately 1 year). Samples from each group in each chamber will be removed at the following intervals: 0 days, 15 days, 30 days, 60 days, 90 days, 180 days, and 360 days. The film material will be checked for relative degradation with visual classification, elemental analysis, infrared spectroscopy, pH, and intrinsic viscosity tests. Any brown powder produced will be weighed and subjected to elemental analysis in order to learn its chemical composition, particularly whether or not it contains any metals that could serve as catalysts for brown powder formation or combustion. As a control for the small size of the vial specimens, we will distribute remaining roll film between the chambers. After the full 360 days, the roll film will be analyzed using the same methods described above.

Finally, to check for impact sensitivity of the brown powder, we will supplement the DSC analyses of brown powder samples from the field and from the accelerated aging trials with spectroscopic analyses (infrared and ^{1}H nuclear magnetic resonance), the BAM Fallhammer Test of Impact Sensitivity, and the BAM Friction Test of Friction Sensitivity. First, on site, we will try to replicate results of Edge *et al.* with infrared spectroscopy supplemented by ^{1}H nuclear magnetic resonance, to see if our brown powder samples also appear to consist primarily of nitrogen and oxygen with some iron. Additionally, we will send samples to Columbia Analytical Services for analysis with inductively coupled plasma atomic emission spectroscopy (ICP-AES). ICP-AES is very sensitive to the presence of trace metals (parts per million levels), allowing us to better judge whether metals are present, and if so, how they contribute to (or conversely diminish) safety risks. Finally, we will send samples to Chilworth Global, a safety services firm, to test for impact and friction sensitivity. To test for impact sensitivity, samples will be subjected to impact from a falling weight using the BAM Fallhammer method. To test for friction sensitivity, samples spread on a porcelain plate will be dragged beneath a weighted porcelain peg following the BAM Friction method. The Fallhammer test looks for the lowest *energy* at which a flash, flame or explosion can be observed; the Friction test looks for the lowest *force* at which a flash, flame or explosion can be observed. Taken together, all of these tests should greatly enrich our understanding of the brown powder's chemical composition, and of the safety risk it poses.

During the ongoing laboratory experiments, we will continue to work on the literature review project initiated by Heckman. Historical sources about nitrate film and interviews with nitrate archivists will supplement the empirical work.

In addition to producing a white paper translating our results into terms readily understood by humanities-trained archival professionals, this project will propose amendments to *NFPA 40, Standard for the Storage and Handling of Cellulose Nitrate Film*, and *ISO 10356—Cinematography—Storage and handling of nitrate-base motion picture films.* An advisory board composed of representatives will review our experimental progress and all the written material we generate, with a special focus on amendments to the standards.

The members of our advisory board are (see also *Appendix C*: *Advisory Board Commitment Letters and Résumés*):

Douglas Nishimura, Image Permanence Institute
Mike Pogorzelski, Academy Film Archive

Ed Stratmann, George Eastman House

Work Plan

Project activities will be divided into four groups: a laboratory group, a history group, a conservation group, and a dissemination group.

Activities in the laboratory group will be led by Mahesh Mahanthappa, with assistance from the Chemistry RA in collaboration with the Comm Arts RA. Activities in the historical group will be led by Vance Kepley, with assistance from the Comm Arts RA. Activities in the conservation group will be led by Maxine Ducey, with assistance from Kathleen Mullen and the Comm Arts RA. All staff will contribute to activities in the dissemination group.

All staff will meet in January 2012 to discuss project goals, and to finalize plans for each activity area. Objectives for each phase of investigation will be set, and a regular schedule of staff meetings will be established. Minutes for this and all subsequent meetings will be sent to the advisory board for feedback.

Phase 1: Preparation (3 months)

The conservation group will begin by soliciting additional sample films and cans from institutions with nitrate film holdings. Beginning with the on-site samples (and continuing with any additional donated samples), the conservation group will photograph and catalog each roll of film, noting physical condition, manufacturer names, edge codes, and dates of manufacturing. Unique identifiers will be assigned to each film, each can, and each brown powder sample. Any accumulated brown powder will be physically segregated from the films, but intellectually linked in the project catalog. Cans will be photographed and cataloged, as well.

The laboratory group will begin by finalizing experimental design. It will order necessary supplies, modify and calibrate equipment, and secure contracts for outsourced analyses. As the conservation group finishes with cataloging and photographing the donated film samples, the laboratory group will prepare experimental specimens. Experimental specimens will be assigned unique identifiers linked to those in the conservation catalog.

The history group will finalize the project bibliography and begin to compile sources. It will create a list of interview subjects and questions.

The advisory group will review staff meeting minutes, experimental designs, and the bibliography.

Rough timeline:

- January 2012: experiment design finalized by Mahesh Mahanthappa and the Chemistry RA, and approved by members of the advisory board

- January-March 2012: films and cans collected, inspected, photographed and cataloged by the Comm Arts RA under the supervision of Maxine Ducey and Kathleen Mullen

- January-March 2012: bibliography compiled by the Comm Arts RA under the supervision of Vance Kepley

- January-March 2012: interview questions written and interview subjects identified by the Comm Arts RA under the supervision of Vance Kepley

- February 2012: supplies ordered, equipment prepared, and contracts confirmed by Mahesh Mahanthappa and the Chemistry RA

- March 2012: specimens prepared by the Chemistry RA under the supervision of Mahesh Mahanthappa, and with assistance as needed from the Comm Arts RA

Phase 2: Research (1 year)

The laboratory group will implement the procedures described in the methods section, above. The 360-day accelerated aging test will be started. Organic elemental analysis, infrared spectroscopy, and pH tests will be repeated on aging test samples collected on days 0, 15, 30, 60, 90, 180, and 360. During the ongoing accelerated aging trial, the laboratory group will conduct DSC trials with film and brown powder specimens. They will also send brown powder specimens out for BAM Fallhammer, BAM Friction, and ICP-AES testing.

The conservation group will photograph and visually classify all post-experimental accelerated aging samples. At the end of the experimental phase, the conservation group will safely dispose of all materials.

The history group will conduct interviews, and compile and review all remaining sources listed in its bibliography.

The advisory board will review staff meeting minutes.

Rough timeline:

- April 2012-April 2013: accelerated aging tests for brown powder production
    - Environmental chambers monitored by the Chemistry graduate student RA under the supervision of Mahesh Mahanthappa, with assistance as necessary from the Comm Arts RA
    - Samples collected in early April, mid-April, early May, early June, early July, early October, and early April 2013
        - Independent visual classification by Maxine Ducey, Kathleen Mullen, and Comm Arts RA

        - Photography by the Comm Arts RA, under the supervision of Maxine Ducey and Kathleen Mullen
        - Organic elemental analysis, infrared spectroscopy, intrinsic viscosity, pH, DSC, and TGA tests by the Chemistry RA under the supervision of Mahesh Mahenthappa, with assistance as necessary from the Comm Arts RA

- April 2012-Apr 2013, impact sensitivity tests of brown powder samples collected from the field

    - Infrared spectroscopy and ^{1}H nuclear magnetic resonance by the Chemistry RA under the supervision of Mahesh Mahanthappa, with assistance as needed by the Comm Arts RA
    - Samples sent out for BAM Fallhammer, BAM Friction, and ICP-AES tests by the Chemistry RA under the supervision of Mahesh Mahanthappa

- April 2012-May 2012, impact sensitivity tests of any brown powder samples that have accumulated in the accelerated aging trials

    - Samples collected in early April, mid-April, early May, early June, early July, early October, and early April 2013

        - Infrared spectroscopy and ^{1}H nuclear magnetic resonance by the Chemistry RA under the supervision of Mahesh Mahanthappa, with assistance as needed by the Comm Arts RA
        - Samples sent out for BAM Fallhammer, BAM Friction, and ICP-AES tests by the Chemistry RA under the supervision of Mahesh Mahanthappa

- April 2012-April 2013, bibliographic sources obtained and reviewed by the Comm Arts RA and Vance Kepley

- April 2012-April 2013, interviews conducted and transcribed by the Comm Arts RA under the supervision of Vance Kepley

Phase 3: Analysis (1 year)

Analysis will overlap with research, starting before the completion of the experimental accelerated aging test.

The laboratory group will finish statistical analysis of all data collected during the experimentation phase.

The historical group will annotate its bibliographic entries.

The dissemination group will draft a white paper, amendments to *ISO 10356*, and a proposal for amendments and additions to *NFPA 40*. It will present results at conferences.

As relevant, groups will also collaborate on manuscripts for publication in their respective fields.

The advisory board will review staff meeting minutes, data sets, and drafts of all written materials.

Rough timeline:

- June 2012, results from the impact sensitivity tests of the brown powder samples collected from the field analyzed by Mahesh Mahanthappa and the Chemistry RA; reviewed by members of the advisory board

- June 2012-April 2013, bibliographic entries annotated by the Comm Arts RA, under the supervision of Vance Kepley

- July 2012, data from the first five sets of samples collected from the accelerated aging experiments (days 0, 15, 30, 60, and 90) analyzed by Mahesh Mahanthappa and the Chemistry RA; reviewed by members of the advisory board

- August 2012, preliminary results presented at the annual conference of the Society of American Archivists (SAA) by Maxine Ducey and other members of the dissemination group

- August-September 2012, proposal for amendments and additions to *NFPA 40* drafted by Mahesh Mahanthappa, Maxine Ducey, Kathleen Mullen, and the RAs; reviewed by members of the advisory board

- November 2012, proposal for amendments and additions to *NFPA 40* submitted for the 2014 two-year review cycle (deadline November 23)

- November 2012, preliminary results presented at the annual conference of the Association of Moving Image Archivists (AMIA) by Maxine Ducey and other members of the dissemination group

- May 2013, annotated bibliography reviewed by members of the advisory board

- June 2013, final data from the accelerated aging experiments (inclusive of days 180 and 360) analyzed by Mahesh Mahanthappa and the Chemistry RA; reviewed by members of the advisory board

- June 2013, preliminary results presented at the annual conference of the American Institute for Conservation of Historic and Artistic Works (AIC) by Kathleen Mullen and other members of the dissemination group

- May-June 2013, white paper, and *ISO* & *NFPA* amendments drafted by the RAs with input from the full dissemination group; reviewed by members of the advisory board

At the end June 2013, the RA positions will close. Dissemination of project deliverables will continue over the course of another year, through June 2014. See *Dissemination* below.

Dissemination

Wide dissemination of project results is imperative to the success of this project. Between June 2013 and June 2014, the dissemination group will continue to publicize the study results.

The project white paper will be completed, and made available for free download as a PDF on the AMIA Nitrate Film Committee page (www.amianet.org/groups/committees/nitrate). Its availability will be publicized in the AIC, SAA, and AMIA newsletters, and on their respective email listservs.

Amendments to *ISO 10356* will be submitted to the International Standards Organization.

Staff will make second visits to all three major archival and preservation conferences—SAA, AMIA and AIC—to present final results and recommendations.

Results will be submitted for publication. Targeted journals will include *Journal of the American Institute for Conservation, Restaurator, The Moving Image, The American Archivist, Journal of Photochemistry and Photobiology,* and *International Journal of Polymer Science*.

All data and written material generated over the course of the project will be made available for free download through Minds@UW; see *Sustainability of Project Deliverables and Datasets*, below.

Sustainability of Project Deliverables and Datasets

Project staff are equally committed to transparency, and want to make the methodology used in the project, and the data it generates, easily accessible. All documentation of project methods and all data generated by the project will be preserved by the WCFTR. It will also be stored on Minds@UW, a UW-hosted digital collection for faculty research. Minds@UW is a University of Wisconsin Digital Collections (UWDC) project that provides a stable, scalable, and sustainable platform for the delivery and long-term management of digital content. Materials posted to Minds@UW feature permanent, unbreakable URLs, and indexing by Google, GoogleScholar, and other specialty academic search engines.

Staff

Vance Kepley is Professor in the UW Department of Communication Arts (Film Studies), serving his second, non-consecutive term as Director of the Wisconsin Center for Film & Theater Research. With four years experience as Chair of the Department of Communication Arts, he is also an able and efficient administrator. He is the author of two books and numerous articles on film history. He will give 10% of his time to the project.

Mahesh Mahanthappa is Assistant Professor of Chemistry at UW-Madison. His research interests span macromolecular chemistry and physics, evidenced by publications by his research group in journals such as *Macromolecules* and *Journal of Polymer Science*. He is particularly interested in bringing chemistry topics to a wider audience. He has already partnered with the Institute for Chemical Education and the National Science Digital Library on a project highlighting the social and political impacts of commodity plastics, and he is actively pursuing partnerships in art conservation. He will give 10% of his time to the project.

Maxine Ducey is Senior Special Librarian (Archivist) at the Wisconsin Center for Film & Theater Research. She has spent 30 years collecting, preserving, and providing access to the films of the WCFTR and the WHS. A founding member and one-time president of AMIA, Maxine closely follows developments in the field of moving image preservation. She will give 15% of her time to the project.

Kathleen Mullen is Director of Preservation at the Wisconsin Historical Society. She holds an MA in Conservation from the University of Texas, Austin, and has more than 8 years of experience in the conservation field. She is charged with preservation research and development for all materials in WHS collections.

Additionally, this project will fund two 50% Research Assistantships, one each in the Chemistry and Communication Arts Departments.

See also *Appendix D*: Staff Résumés and Position Announcements.