To Repair or Despair?

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NO ARCHIVIST will dispute that his primary responsibility is the physical welfare of his archives. It was therefore fitting as well as symbolic that the first article of the first issue of the *American Archivist* was on the subject of repair and preservation. The profession owes a debt of gratitude to L. Herman Smith of the Department of Manuscripts in the Huntington Library, California, for a very comprehensive and completely factual report. Smith spent a year investigating methods of document restoration in Europe; and his report, entitled "Manuscript Repair in European Archives," [1] perhaps makes more interesting reading now than it did 22 years ago. What a panorama of repair processes he saw in Europe then!

The administration of archives has made great strides during the last 20 years. The spirit of progress is clearly reflected in the title of Ernst Posner's presidential address to the Society of American Archivists last year, "What Then Is the American Archivist, This New Man?" [2] In many other countries too, wherever the burden of tradition is not too heavy, the new spirit and new approach are active, seeking and finding new solutions to both old and new problems. The aim of European policy seems usually to be the concentration of repair work on the so-called "ancient classes." The question of modern papers is chiefly considered to be a matter for the creator of the papers — the administrator should ensure that he uses only tough, good-quality paper when he produces records.[3] To those archivists whose collections are largely composed of relatively modern papers, these views appear quite unjustifiable and fit only for the sort of ostrich mentality that seeks to bury its head alternately in the sands of the past and the sands of the future.

Beset with stupendous and pressing difficulties, the custodian of a vast accumulation of modern records cannot wait an indeterminate time before tackling the problem of rehabilitation. The

[1] *American Archivist*, 1:1-22 (Jan. 1938). This report is of an investigation made in 1935.

[2] *American Archivist*, 20:3-11 (Jan. 1957).

[3] See Hilary Jenkinson, "The Principles and Practice of Archive Repair Work in England," in *Archivum*, 2:31-41 (1952).

various traditional methods of European repair were examined and discarded as unsuitable for mass production and hence prohibitively expensive for application on a large scale. Doubt was cast, moreover, on the chemical stability of some of the substances and materials employed. The stage was set for some new approach to the problem. A revolution was in order. Lamination with cellulose acetate was accepted as the answer. Roger Ellis of the Public Record Office, London, has said that in matters affecting repair processes, the chemist is "sometimes a dangerous guide but always a valuable ally." [4] One cannot but feel that a chemist when confronted with Smith's report would not speak of archivists with the same measure of tact and diplomacy! The speculation is interesting, as it was against this background that chemists at the National Bureau of Standards in the United States pioneered the use of cellulose acetate foil in the field of document restoration. On the advice of the Bureau, the National Archives in Washington embarked on an extensive program of lamination, and thus was born a controversy where Ellis's remark could be regarded by the disputants as either prophetic or merely platitudinous.

The new process aroused worldwide interest. On the one hand it was regarded as "eminently satisfactory," [5] and the answer to practically all the problems of document repair. On the other hand it was subjected to a heavy barrage of criticism. Most of this criticism came from European archivists, who made repeated references to a factor called the test of time. These criticisms were brushed aside, partly because no one made any attempt to define what was meant by the test of time and partly because the critics themselves were regarded with not a little suspicion for their seemingly unrealistic attitude towards present-day problems. Besides, cellulose acetate had the blessing of most fair-minded chemists, being regarded as a completely stable substance that in no way could be toxic to paper.

There are, however, critics of the process who base their objections on concrete observation rather than on hypothetical and indefinite assumptions about the test of time. For example, Joseph Broadman, speaking of ". . . the reasons why cellulose acetate cannot be considered a permanent plastic," says:

In the first place, all cellulose acetate films known or used commercially contain a plasticizer. A plasticizer is usually a volatile liquid or solid which is incorporated with the cellulose acetate to provide a finished product of the

[4] Roger Ellis, *The Principles of Archive Repair* (London School of Printing and Graphic Arts, 1951).

[5] B. W. Scribner, *Protection of Documents With Cellulose Acetate Sheeting*, p. 2 (U. S. National Bureau of Standards, *Miscellaneous Publication* M 168, 1941).

desired flexibility, toughness and life. Cellulose acetate *per se* is quite brittle and cannot be easily produced or fabricated. In time these plasticizers tend to exude from the plastic sheet . . . [the plasticizer] . . . is then lost to the plastic along with its beneficial effects.[6]

Again, H. J. Plenderleith, Keeper of the British Museum Research Laboratory, writes:

Any hesitation in recommending the cellulose acetate process for the lamination of valuable documents is concerned with the fact that, while cellulose acetate may be accepted in itself as innocuous and durable, the sheets used for laminating contain a relatively high percentage of plasticizer, and it is by no means certain that this will remain in the film indefinitely, or indeed that one or other of the plasticizers used may not in some as yet undefined way be deleterious to the paper.[7]

Up to about a third of the total weight of a sheet of cellulose acetate foil may be composed of plasticizer; to call this material cellulose acetate foil is, therefore, largely a misnomer. It is clear that should the plasticizer for some reason exude or evaporate, the remaining sheet would materially differ from the original foil. The degree of adhesion to the document would probably be weakened, and the foil by itself would become relatively brittle.

About 3 years ago some of the laminated documents in the National Archives in Washington appeared to be giving signs of trouble; and an inquiry, sponsored jointly by the National Archives, the Library of Congress, the Army Map Service, and the Virginia State Library, was instituted. The inquiry is being carried on by the United States National Bureau of Standards. The first publicity on this project was given at the annual meeting of the Society of American Archivists at Nashville, Tennessee, in October 1955, when W. K. Wilson of the Bureau of Standards pointed out that the plasticizer of some of the cellulose acetate foil in the National Archives had proved to be fugitive. The main objective of the investigation now in progress is to develop information that would establish specifications for stabilizing the plasticizer in the foil.

An interesting and curious aspect of the discussion at Nashville was the attitude adopted by the users of the restorative process developed by W. J. Barrow of Richmond, Virginia. All staunchly supported the Barrow method, and none had the slightest deterioration in repaired documents to report. Papers that had been repaired

[6] Joseph Broadman, *Cellulose Acetate Sheetings — A Critical Analysis* (New York, 1946).

[7] H. J. Plenderleith, *The Conservation of Antiquities and Works of Art* (Oxford University Press, 1956).

with cellulose acetate foil 18 years ago and used on an average of 400 times a year were said to be as good as the day they were repaired.

On the other hand the situation at the National Archives has not been so happy. T. R. Schellenberg, Assistant Archivist of the United States, National Archives, quotes D. L. Evans (now Deputy Keeper in the Public Record Office, London) "For what guarantee is there of the permanence of the qualities of this new material: that with the passage of time, its transparency will not be marred by discoloration and its flexibility give way to brittleness?" [8] Schellenberg then observes, "After twenty years of experience with the lamination process the National Archives has found this skepticism to be a least partially justified." [9]

There seems to be a good deal of confused thinking about the Barrow method as compared with the National Archives process of lamination. This is typified in A. E. Minogue's remark, "W. J. Barrow of the Virginia State Library in Richmond has developed a less expensive lamination machine which is different from the flatbed hydraulic press in use at the National Archives, but the result of the processing is similar." [10] The truth of the matter is that there is little similarity between the equipment, the process, or the results of the two methods. The only common feature is that both use cellulose acetate foil.

The National Archives employs a steam-heated flat-bed hydraulic press. Documents are usually laminated with cellulose acetate foil 0.00088 inches thick without any reinforcing tissues. As the foil has very little tear resistance the restored document is not much stronger than before lamination. The temperature and time cycle required for laminating are particularly noteworthy. "For affixing [cellulose acetate] sheeting without adhesive, the temperature range is commonly 150° to 175°C, the pressure range is from 300 to 2,000 pounds per square inch, and the time required is from 3½ to 30 minutes." [11] In short the temperature, the pressure, and the time are all highly variable factors. The foil can obviously develop its full adhesive properties only when it is molten. This important consideration is fully recognized in the Barrow method, where the foil is first melted in an oven and then subjected to a

[8] D. L. Evans, "The Lamination Process — A British View," in *American Archivist*, 9:320 (Oct. 1946).

[9] T. R. Schellenberg, *Modern Archives*, p. 166 (Chicago, 1956).

[10] Adelaide E. Minogue, *The Repair and Preservation of Records*, p. 39 (National Archives, *Bulletin* No. 5, 1943).

[11] Scribner, *Protection of Documents*, p. 3.

momentary nip in a roller press. While passing through the roller the foil cools and hardens to become an integral part of the document. That the National Archives has at times found it necessary to expose the foil/document/foil sandwich to heat for several minutes indicates that the melting point of the foil has not been reached and that whatever adhesion takes place is purely the result of pressure. As the foil is not at a sufficiently high temperature to be sticky it is incapable of adhering to the individual fibers of the document. The action of prolonged pressure merely results in a semiplastic foil being forced into the pores of the document. The lower the temperature the longer the exposure to pressure necessary to achieve this type of adhesion. Adhesion of this nature is largely dependent on the locking action of particles of foil in the pores of the paper. Should the plasticizer subsequently prove to be fugitive these particles would shrink and the remaining cellulose acetate would tend to fall away from the document.

Apart from a marked tendency to substitute time of exposure for an inadequate temperature, the method of lamination employed at the National Archives has certain mechanical disadvantages. Basically, a flat-bed press is not compatible with the job of document lamination. H. M. Nixon of the British Museum's department of printed books has pointed out that "the flat-bed type of press has one defect: when a direct vertical pressure is exerted there is always the possibility of trapping a little air between the acetate sheet and the document. Where this occurs a small bubble will be left which may subsequently prove a source of trouble." [12] Apart from inevitably trapping a certain amount of air, which will expand on being heated, there is also the possibility of trapping vaporized plasticizer, as well as the probability, even if the document is only slightly moist, of trapping water, which is converted into superheated steam. As the practice is to cool the press while the documents are still under pressure, these gases are given the opportunity to contract or condense so that the laminate may appear sound. In actuality, the foil has been separated from the document in certain areas by a layer of gas, and these areas remain weak points in the laminate. By the time the foil and the document are brought into close contact on the cooling of the press, the temperature of the foil has dropped to a point where its adhesive properties are practically nil. It is therefore only a question of time and usage before the weakness of these areas becomes apparent to the naked eye.

[12] Howard M. Nixon, "Lamination of Paper Documents With Cellulose Acetate Foil," in *Archives*, 1949, no. 2, p. 35.

In a roller press such as is employed in the Barrow method the possibility of trapping superheated steam, air, and vaporized plasticizer between the document and the foil is eliminated. The addition of two relatively stout sheets of tissue greatly reinforces the restored document. When we consider the possible fugitive nature of the plasticizer in the foil, the Barrow method has a further outstanding advantage. If a sandwich is made of a document, a standard sheet of foil, and 5 sheets of 6½-pound tissue, and if this sandwich is passed through the Barrow laminator, it will be found that all the sheets of tissue are stuck to the document. In the top or fifth sheet of tissue adhesion is confined to small areas; in the fourth tissue the areas of adhesion are large, and in the other three sheets of tissue adhesion appears to be complete. In short, a sheet of foil 0.00088 inches thick has over three times the adhesive properties that are required to weld a single sheet of reinforcing tissue to the document. As the foil is molten when it is fed into the press, the two solid materials involved — the document and the fibers of the tissue — are brought into very close contact by the rollers. It can be shown that the surplus foil in the Barrow tissue/foil/document/foil/tissue sandwich is squeezed through the fabric of the tissue and deposited on the surfaces away from the document. As there is about three times as much adhesive in this operation as is actually required the surplus adhesive is forced by the rollers into a series of waves on top of the tissue. The critical area in the Barrow laminate is between the document and the tissue; it is noteworthy that this area only contains a small fraction of the cellulose acetate foil. Any subsequent loss of plasticizer is therefore not likely to cause a mechanical breakdown because the quantity of this material employed in the critical area is minute. Whereas the flat-bed press will produce a true lamination [13] with cellulose acetate, the Barrow method produces a lamination with tissue.

The foil in the Barrow method, because of the action of the rollers, takes the place of an adhesive. If in the passage of years the plasticizer should dry out, the tissue would still be held to the document by the pure cellulose acetate. To be sure, the remaining cellulose acetate would be relatively brittle, but so is any good flour paste when it is dry. There is no reason to suppose that the minute quantity of pure cellulose acetate in this critical area between the document and the tissue will behave mechanically in a different way from flour paste. Apart from its ease of application, one of the

[13] The word lamination has been used throughout to imply the presence of a definite lamina or layer.

greatest advantages of cellulose acetate over flour paste is that its high refractive index improves the transparency of the reinforcing tissue. The bookbinder's and repairer's old adage that adhesives are meant to stick things together and not keep them apart is as true with cellulose acetate foil as with any other adhesive. If cellulose acetate sheeting could be obtained one-half or one-third as thick as the standard 0.00088 inch foil, it should produce better results in the Barrow method. If a manufacturer could be persuaded to make a foil about 0.0003 inches thick, ready fabricated with a suitable reinforcing tissue, it would go a long way in speeding up repair work.

There is one other major difference between the Barrow and the National Archives processes. Barrow insists that papers to be restored should be deacidified. The actual method of deacidification also has the effect of flattening as well as cleaning the document. While deacidification is a great contribution to the science of document preservation, it is considered that sufficient time has not elapsed for the absence of deacidification to be the cause of the deterioration of restored documents in the National Archives.

It must not be assumed from the foregoing remarks that lamination in the National Archives has resulted in irreparable damage being done to irreplaceable records. The fact is, however, that whereas the chemistry of both the National Archives and Barrow processes is identical, the mechanics of the two are quite different. There is no evidence that any documents repaired by the Barrow method are giving mechanical trouble, but this cannot be said of those repaired in the National Archives. The question then arises: Is it necessary for the United States Bureau of Standards to develop a new specification for foil which would contain antioxidants, buffers, stabilizers, and other untried substances in an effort to retard the loss of plasticizer? May it not be preferable to develop a foil with an even more fugitive plasticizer that, while lowering the melting point of the foil, evaporates a short time after application?

Scribner's attitude towards the vital factors of temperature, time, and pressure has been noted. Arthur E. Kimberley adopts the same view: "The heating time may vary 3½ minutes to 30 minutes at 40 pounds steam pressure while the pressure necessary ranges from 300 pounds per square inch to 2,000 pounds per square inch." [14] And Miss Minogue says: "It is impossible to lay down general rules for the lamination of the various types of materials encountered,

[14] Arthur E. Kimberley, "Repair and Preservation in the National Archives," in *American Archivist*, 1:115 (July 1938).

because individual presses vary and the steam pressure varies from day to day. More time is required for heating when steam is at low pressure."[15] Barrow states that ". . . the approximate temperature range is from 315°F to 320°F, and a pressure of over 700 pounds per square inch. . . . The application of this film should be made with only a precision-built piece of apparatus, which controls very accurately the heat and pressure." The Barrow press has a thermometer, which, while indicating the temperature of the platens, does not give the temperature of the document and foil; in the absence of a pressure gage there is no way of determining what pressure is applied and there is no timing device to ensure that the document is not given an over- or under-exposure to heat. Archivists would do well to determine the exact temperature at which cellulose acetate foil develops its greatest adhesive properties. Presses should have thermo-couples, which should indicate the exact temperature of the document, *not* the platen or oven. Linked with the thermo-couple should be an accurate timing device. A pressure gage is also a necessity. The present rough-and-ready, rule-of-thumb methods of repairing documents with cellulose acetate foil must inevitably lead to accidents and to the damaging of irreplaceable documents.

It is of the utmost importance that the whole process of repair should be subjected to checks and counter checks. The Public Record Office in London has a repair register with an index capable of giving the repair history of any document in a matter of minutes. This system could well be adopted by all institutions. Every archival institution should have a small laboratory capable of conducting simple tests to determine the degree of acidity in a sample of paper, the presence of nitrate in foil, and so on. All these tests, like the standard tests for residual hypo in photography, are largely a matter of common sense; they do not require the services of a fully qualified chemist. A small manual describing such a laboratory and the checks and tests that should be undertaken would be useful to many archivists.

My criticisms of present day repair processes involving the use of cellulose acetate foil have been voiced in a spirit of constructiveness. There is no doubt that the processes need refinement. On the credit side, however, the use of cellulose acetate foil in conjunction with a good quality of tissue can result in an outstanding product — one that is not only chemically, physically, and economically far superior to that of the traditional method of silking, but is esthet-

[15] Minogue, *Repair and Preservation*, p. 34.

ically more pleasing than the product of any other method of repair.

There is, however, one important aspect in which document restoration using cellulose acetate foil does not appear to have justified early hopes and expectations. At one time it was thought that the new process would permit the treatment of the great mass of modern records; but, alas, this seems to be beyond the economic capacity even of America. The process is relatively slow and expensive. What then is to happen to the vast numbers of modern records that are crumbling to dust? Evans says ". . . it is the edge of a poor paper that first becomes brittle and yellow. The obvious remedy is to frame the documents with a new paper of 'record' quality. That, however, is admittedly a skilled job and a slow one." [16] The framing of these papers would, over a period of time, result in further considerable damage due to the varying degrees of expansion between the document and its frame. Evans is also wrong in supposing the disease is confined to the edges. Admittedly the edges deteriorate first, under the action of light and oxidation, but it must be remembered that the entire document is "sick" because of the poor quality of the material of which it is made. Neutralization of any active elements in the document that may be aggravating or causing deterioration, together with reinforcement over the entire surface of the document, is the only hope of preserving the original. The archivist charged with the permanent preservation of masses of unstable material is confronted with a problem to which there is at present no answer.

The existing solution is to microfilm the documents and then either retain or dispose of the originals, according to their "intrinsic" value. Archivists at the National Archives in Washington have done much pioneer thinking along these lines. Instead of attempting to repair some originals, they microfilm them and make positive copies of the film available for purchase as microfilm publications. The fact that this film becomes available in several centers is particularly useful in a large country such as the United States. Microfilm is virtually the same material as cellulose acetate foil but contains different plasticizers. There is no reason to suppose, provided the master negatives are properly stored and periodically inspected, that the information on film could not be preserved for thousands of years.

When an archivist decides to destroy his original material and retain only a copy of it on film, he is obviously taking a grave step. That he appears to have no alternative does not in any way absolve

[16] Evans, "Lamination," in *American Archivist*, 9:322 (Oct. 1946).

him from his responsibilities. The modern archivist can no longer afford to be an impartial custodian of his papers. He has to say a great deal about the type of material he is prepared to accept in his archives, and he must be prepared to formulate sound reasons for his decisions. In the same way he should endeavor to formulate criteria for the logical elimination of original material that cannot be preserved.

It would be helpful if he could create a systematic nomenclature defining the "intrinsic" value as well as the physical condition of his various classes of records. It might be helpful if he should indicate their physical condition by the symbols, A, B, and C and the measure of their intrinsic value that would have a bearing on his decision to preserve or not to preserve the originals by the symbols, I, II, and III. Symbol A would indicate that the documents were in good physical condition, B that they required some rehabilitation, and C that they required extensive repair to ensure their preservation. Documents of class I would be those judged to be worth preserving in the original at almost any cost; class II would be those that it would be desirable to preserve in the original if reasonably possible, and class III would be those of which the original might be sacrificed should a copy be preserved. A series of interesting permutations can be evolved by combining the various classes of physical condition with the various classes of intrinsic value. It would be interesting to compare the definition of a class I with that of a class III document. Thoughts along these lines could conceivably rationalize a repair program while preventing an institution from embarking on a repair program wholly beyond the means of the country or state supporting it.

The rapid deterioration of poor-quality modern papers is a problem that is also common to libraries. For many reasons, but particularly because of the uniform size of the pages of a book, the problem of preservation in libraries is less complex than it is in archives. For example, it should be possible to feed the pages of a book into a rotary camera once the edges of the pages had been uniformly trimmed. It is conceivable that a whole 300-page volume could be reduced to microimages on a 4″ x 6″ double emulsion coated card, and that the whole operation could be carried out automatically. The Ford Foundation has recently provided $5,000,000 to create a Council on Library Resources. This council, under the inspired leadership of Verner W. Clapp, formerly Chief Assistant Librarian of Congress, is destined to make a major contribution to the physical preservation of printed material. Is it too much to hope that one of the great foundations will provide funds for research not only in the means of preserving irreplaceable archives but also in the best methods of preserving the information they contain?

And to the question: Is an archivist to repair or despair? There seems little doubt that in a great number of cases he will be forced to despair of repairing and to find some other method of preserving the information in the records.

Comments On Mr. Turner's Article

By James L. Gear [17]

Mr. Turner's "To Repair or Despair" is a most interesting and thought-provoking article. His theories and observations about the lamination process should stimulate archivists to analyze objectively their present methods and assumptions. Many of the points he makes are sound, and all deserve careful consideration. Some raise questions that cannot be summarily answered but rather suggest lines for future investigation.

In 1954, after nearly 20 years of laminating experience, the National Archives found it desirable to review its own methods; and, with the Library of Congress, the Army Map Service, and the Virginia State Library as joint sponsors, it asked the National Bureau of Standards to carry out a program of investigation. This program was not only to develop specifications for laminating foil but to look into such other important matters as the value of adding tissue to the laminate, the desirability of deacidification, and the relative merits of different kinds of equipment. The Bureau has now substantially completed its work, and in the course of doing so it has taken up specifically some of the questions and criticisms in Mr. Turner's article. My comments below are based on the findings of the Bureau and on my own laboratory experiments in the National Archives. I have set them down approximately in the order in which the related questions are raised by Mr. Turner.

Many critics of lamination have discussed plasticizers, volitalization of plasticizers, and the supposed resultant effects of volitalization, such as brittleness and delamination. The kind of plasticizer incorporated in a film depends on the requirements of the end product. In films for archival use a plasticizer is incorporated for one basic purpose — to lower the softening temperature at which cellulose acetate can be bonded to paper. The fact that most of the plasticizer will in time be lost has little effect on brittleness

[17] Mr. Gear is Chief of the Document Restoration Branch, National Archives.

or delamination. Cellulose acetate film of the thickness commonly used for archival lamination (.88 mils) is quite flexible without plasticizer. Folding endurance tests of plasticized and unplasticized films show this to be true. The Hercules Powder Co. has stated that toughness is a property inherent in cellulose derivatives and gives data on 3-mil unplasticized films that show toughness and flexibility to depend largely on the viscosity and the acetic acid content of the cellulose acetate flake. The folding endurance of the films (as measured in MIT Double Folds) ranged all the way from 15 to 293.[18]

Toughness in film can be defined as the opposite of brittleness; it means strength and firmness with flexibility. Folding endurance tests were made in the laboratories of the Bureau of Standards on a plasticized and an unplasticized film cast from the same cellulose acetate flake and on a commercial film suitable for lamination. The resultant data were as follows:

	Thickness (mils)	Number of MIT Double Folds
Film #1, unplasticized	1.1	1,393
Film #2, plasticized	1.5	806
Commercial plasticized film	.88	1,419

Another commercial laminating film .88 mil thick gave a value of 1,444 MIT Double Folds; yet the same film after being embedded in activated charcoal at 50°C for 46 days, to facilitate volitalization and removal of the plasticizer, gave a value of 1,864 MIT Double Folds. Despite the variation in the thickness of the films tested, the results give a fair indication of the relative flexibility of plasticized and unplasticized films.

So far there have been no data to support the theory that delamination would result from the loss of plasticizer. The loss of plasticizer from a film kept at room temperature would be comparatively slow, depending on the plasticizer, its vapor pressure, and its compatability with the cellulose acetate. We attempted, without success, to bring about delamination by embedding laminated paper in charcoal at 50°C for 30 days. There was no delamination or loosening of the bond in any of the samples.

Although the final specifications for archival film will cover far more than merely the plasticizer used — including such factors as the degree of substitution, viscosity, an acid acceptor, an ultraviolet absorber (which would also act as an antioxidant), and

18 Hercules Powder Co., *Hercules Cellulose Acetate — Properties and Uses* (1954 ed.).

capacity to withstand accelerated aging tests — the importance of the kind of plasticizer used must not be underestimated. DeCroes and Tamblyn found that the plasticizer is often one of the principal contributors to the breakdown of cellulose esters and that the breakdown is partly oxidative.[19] Plasticizers are often more easily oxidized than the cellulose ester. It will therefore be important to settle on plasticizers that do not readily oxidize.

Laminating presses differ in the details of their operation, but all have time, temperature, and pressure as variables. It was suggested in 1941 that the range of pressure for laminating paper should be from 300 to 2,000 pounds per square inch and the range of heating time from 3½ to 30 minutes.[20] In the laminating operations of the National Archives today the pressure range used is from 300 to only 500 pounds per square inch and the range of heating time (starting from room temperature and rising to 150°C) is only 2 to 2½ minutes. Under these conditions adhesion can be achieved without difficulty, for in lamination adhesion depends on the "creep" or softening of cellulose acetate. The softening temperature is not fixed but depends on time of heating, rate of heating, pressure, and method of noting the end point. Moelter and Schweizer used a creep test in which the film was held under tension during heating at a constant rate of 2°C per minute.[21] They obtained data on several plasticizers, calculated the softening point depression constant for several types of plasticizers, and developed the equation $t = to^{e-kn}$ from their experimental data. In this equation t is the softening temperature in degrees centigrade of the film containing n moles of plasticizer, to is the softening temperature of the acetate flake, and k is the softening point depression constant. Graphical representation of the data gives the softening temperature. Using this equation, we have calculated the softening point of laminating film used by the National Archives at 117°C, well below the temperature attained in the process. Moelter and Schweizer also found that the softening temperature increases slightly with an increase in the speed of temperature rise. If time, temperature, and pressure are variables, the fairly wide range in which lamination could be achieved may also perhaps depend on the kind of paper being laminated; and for a given paper, a time of 2½ minutes, 300 pounds per square inch of pressure, and a tem-

[19] G. C. DeCroes and J. W. Tamblyn, "Protection of Cellulose Esters Against Breakdown by Heat and Light," in *Modern Plastics*, Apr. 1952.

[20] Scribner, *Protection of Documents*.

[21] G. M. Moelter and E. Schweitzer, "Heat Softening of Cellulose Acetate," in *Industrial and Engineering Chemistry*, vol. 41, no. 4 (Apr. 1949).

perature rising to 140°C may produce a bond as strong as that which could be achieved in 2 minutes, at 400 pounds per square inch with a maximum temperature of 150°C. It would be interesting to determine the bond achieved by a pressure of only 50 pounds at a temperature of 100°C for a week and then to embed the laminate in activated charcoal at 50°C for a month and redetermine the strength of the bond.

Mr. Turner says that cellulose acetate has very little tear resistance. Here a distinction must be made. There are two kinds of tear: edge tear and internal tear. The edge tear resistance of a film is much higher than its internal tear resistance, and the same observation applies to a document laminated with cellulose acetate alone. When 6½-pound tissue is used to reinforce a laminated document the edge tear resistance is only ½ the internal tear resistance of the reinforced document, but the edge tear resistance of the tissue-reinforced document is higher than that of the paper alone. Tissue reinforces a weak paper and therefore serves a useful purpose. The National Archives has been using 6½-pound tissue for the reinforcement of all laminated documents since November 1955. Before that time tissue was used on about 25% of all laminated documents.

Air bubbles do occasionally develop in a flat-bed press, but not often enough to constitute a serious disadvantage. The bubbles are clearly visible when the laminate is taken from the press so that it is necessary only to break the bubble with a pin and put the sheet back into the press. The National Archives now uses teflon instead of matte finish steel plates as separator release sheets, and has had no recent instances of bubbles.

The fact that an .88 mil film will penetrate 5 sheets of tissue is not surprising, and recent experiments in the National Archives have shown that it will do so in a flat-bed press as readily as it will between rollers. Tissue is softer and more porous than paper and pressure causes the softened cellulose acetate to move away from the harder surface of the paper and penetrate the more porous tissue. Penetration of part of the cellulose acetate through the tissue is necessary if the tissue is to be made transparent; insufficient penetration will make the writing on the laminated document hazy and difficult to read as a result of light scattering. It is doubtful whether cellulose acetate penetrates to the same degree when only one sheet of tissue is applied to each side as in normal lamination. The harder surface of the separator release sheets would certainly reduce the penetration. Recent lamination trials with tissue and acetate in a Barrow press, similar to the test described by Turner, failed to produce the same results. A series of sandwiches containing five sheets of tissue, 1 sheet of cellulose acetate, paper, 1 sheet of cellulose acetate, and 5 sheets of tissue were laminated in a Barrow press with heating times of 10, 20, 30, and 40 seconds. The operating conditions, temperature, and pressure were those normally used by the operator of the press. The first three outside sheets of tissue were readily removed. The fourth sheet was partly attached, and in the remaining fifth sheet adhesion was complete. It is possible, of course, that the laminating conditions, that is, the time, temperature, and pressure, were different from those under which Mr. Turner made his experiment.

Mr. Turner's suggestion that a .3 mil film might be better suited to the purpose of laminating paper than the usual .88 mil film prompted us to have cast a series of .3 mil, .4 mil, .5 mil, .8 mil, and 1.0 mil films and subject them to physical tests after lamination. The resulting data are as follows:

	Film only (1 sheet, no tissue)	Laminate				
	Tensile at break lbs. per 15 mm. strip	Tensile at break lbs. per 15 mm. strip	Elongation at break %, 15 mm. strip	Edge Tear lbs.	Internal Tear Grams	Bursting Strength Points
Paper alone		6.0	2.2	.3	26.8	10
Tissue alone		4.3	2.3	*	12	7
.3 mil	1.15	27.0	3.0	.46	81	42
.4 mil	1.58	27.3	3.2	.48	85	47
.5 mil	2.16	28.3	3.1	.54	82	44
.8 mil	4.7	33.0	3.5	.73	80	54
1.0 mil	5.8	33.4	3.4	.95	92	**
.88 commercial film	4.4	29.1	3.7	1.1	88	59

* No accurate measure obtained.
** Not enough samples for this test.

From the above tabulation it is apparent that a .3 mil film is much better than one might expect. The major strength is probably due to tissue reinforcement, although this has not been proved. In actual use, however, .3 mil film would not be practicable. Because of its extreme thinness it does not seem to penetrate the tissue during lamination enough to render the tissue nearly transparent. It is also so thin that static charges cause it to cling to almost everything, making handling and application more difficult. This would increase processing time and therefore the overall cost of lamination. To manufacture a ready combined sheet of cellulose acetate and tissue would be difficult, and the effectiveness of the product would be doubtful.

One of the important attributes of permanent paper is low acid content, for it has long been known that highly acid papers deteriorate more rapidly than papers having less acid content. General observation suggests that acidic papers are subject to degradation during the process of lamination; and, therefore, deacidification is highly desirable. DeCroes and Tamblyn show that cellulose ester plastics are unstable in the presence of 0.08% concentrated sulfuric acid and that degradation is counteracted by the use of an acid acceptor.[22] This finding, however, does not mean that all is well if one deacidifies the paper. Laminating films may contain plasticizers that contribute to oxidative degradation; and if this is the case deacidification would only delay degradation of the acetate. The records in the National Archives originated in many different agencies and branches of Government and under many different circumstances. Many of these records were, for years before their transfer to the National Archives, stored under the most deplorable conditions. There is, therefore, probably a wider range of difference in the quality of records to be repaired in the National Archives than in any other institution in the United States. Some of our laminated documents have not stood up so well as was expected, and they have had to be relaminated. Perhaps deacidification would have prevented or delayed the deterioration observed in these documents.

[22] DeCroes and Tamblyn, "Protection of Cellulose Esters," in *Modern Plastics*, Apr. 1952.