FORMAL PROPOSAL FOR PERFORMING SCIENTIFIC RESEARCH ON THE SHROUD OF TURIN



SUBMITTED BY THE
SHROUD OF TURIN RESEARCH PROJECT, INC

FORMAL PROPOSAL FOR

PERFORMING SCIENTIFIC RESEARCH

ON THE

SHROUD OF TURIN

Submitted by the
Shroud of Turin Research Project, Inc.

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by the Shroud of Turin Research Project, Inc.

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DECLARATION

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FORMAL PROPOSAL FOR PERFORMING SCIENTIFIC RESEARCH
ON THE
SHROUD OF TURIN
by
THE SHROUD OF TURIN RESEARCH PROJECT, INC.

INTRODUCTION

The Shroud of Turin Research Project, Inc. (STURP) is pleased to submit a formal proposal for performing scientific research on the Turin Shroud in order to finalize its studies begun in 1978. Although much new information concerning the Shroud has been produced as a result of the 1978 investigation, basic issues remain unresolved in a scientifically rigorous sense. For example, the origin of the image and the relationship of the Shroud to the historical Jesus are still unclear. Further, there does not exist sufficient data to define proper conservation procedures for the Shroud. The first two issues have attracted strong interest in the scientific community around the world in recent years, while the third is of obvious importance to those responsible for conserving the Shroud and anyone who, as we, regard the Shroud as a valuable object which should be preserved for future generations.

We are indeed grateful to His Eminence, Cardinal Anastasio Ballestrero, for having given us the opportunity to examine the Shroud with technically sophisticated instrumentation in 1978. That we are again asking for an opportunity to re-examine the Shroud is motivated by the realization, after six years of exhaustive study, that more data is required to responsibly conclude our 1978 studies regarding the issues of (1) conservation, (2) image formation, and (3) relationship of the Shroud to the historical Jesus. Our request is also motivated in part by the knowledge that the 1969 Scientific Commission was granted the privilege of a second examination in 1973. But most of all, we are motivated by a genuine interest in the Shroud as a scientific problem, apart from whatever religious feelings those in our group may or may not have.

There are various respectable Shroud groups in the World, including the famous International Center of Sindonology in Turin, which could contribute significantly to furthering scientific knowledge of the Shroud. We applaud any efforts these groups might make in the future to bring about new understanding concerning the Shroud and we welcome the opportunities for collaboration (as discussed below). For our part, we believe we have much to offer as well. As a multidisciplinary scientific group, we have acquired considerable expertise over the past six years on the Shroud from our 1978 examination and have published on the Shroud many times in reviewed scientific literature.

We therefore request written permission to examine the Shroud at the earliest convenience of His Eminence, compatible with the necessary lead time (about one year from the time permission is granted) required for us to effectively execute the proposed examination procedures. The time period requested to perform all the examinations on the Shroud is three weeks. The

requested location of the examination is the immediate and most convenient vicinity of where the Shroud is permanently maintained in Turin. We request that specific facilities (described below) be provided to us, including whatever security precautions are necessary. Beyond this, there will be no anticipated requests to His Eminence; STURP will provide (1) equipment, (2) personnel, (3) transportation, (4) customs arrangements, (5) data collection, (6) data analysis, and (7) necessary funding for these six items.

HISTORICAL PERSPECTIVES

There has been a developing and venerable tradition during the entire twentieth century of using the techniques of science to study the Shroud. This tradition is the result of a natural and healthy disposition of our modern, technically sophisticated world that, in addition to asking important religious and philosophical questions of meaning, asks complimentary questions of scientific content.

Modern scientific investigations of the Shroud can be said to have begun in May, 1898 when the Italian photographer, Secundo Pia, took the first photographs of the Shroud. For the first time, scientific information resident in the image discolorations was extracted from the Shroud and recorded onto film. This meant that the Shroud image patterns could be studied anywhere in the world without the necessity of making the Shroud available for direct examination. Better photographs were later made by the Italian photographer, Guiseppe Enrie in 1931. Generally speaking, initial studies were made by private individuals, for example Paul Vignon and Pierre Barbet in France. But in the 1950's, as individual studies began to mature, the International Center of Sindonology in Turin (followed by other groups) began to bring individual efforts into open and formal communication. In 1969, and again in 1973, a scientific commission was appointed to examine the Shroud using the techniques of science. The importance of these studies cannot be overstated; scientific investigations of the Shroud had matured to the point where a collective body, rather than independent individuals, sought to extract and analyze various scientific information from the Shroud. The members of the commission, however, published their results as essentially independent papers comprising a single report. In 1978, along with other investigators, a new group from the United States known as STURP was allowed by His Eminence to examine the Shroud. Like the 1969/1973 Commission, STURP conducted its investigations as a multidisciplinary group. But unlike previous investigations, all publications were refereed first by peer members of STURP and then by outside representatives of authoritative science via the normal peer-review process of established and recognized scientific journals. This has afforded the international scientific community with the opportunity to critically examine and evaluate the Shroud as a scientific object. In otherwords, the data gathered in 1978 is now the property of mankind through its permanent, globally disseminated and respected scientific literature. This is an important and essential step for twentieth century society to evaluate the proper philosophical and religious significance of the Turin Shroud.

Thus, scientific research on the Shroud has been continuously active and maturing since 1898. The trend has been to move from individualistic to multidisciplinary team efforts with a peer-review character, important for

aizing the quality of scientific research. This has been nourished by ver increasing scientific awareness and interest by the general public ts present, worldwide proportions (most of which has occurred over the five years). And it is the experience of STURP that there is spread agreement with the decision of His Eminence to allow one of the ch's esteemed possessions to be examined by objective and unbiased ace in 1978.

A review of scientific articles and papers from 1898 to the present, s significant increases in new scientific knowledge concerning the ad following each examination. For example, the photographic imagery of showed the positive/negative characteristic of the Shroud image. The llent photographs by Enrie in 1931 served as the basis for the well- n medical studies of Barbet. The 1969/1973 examination indicated that Shroud image resided on the surface of the cloth and the removed frag- s allowed important textile evaluations to be performed. Finally, the examinations determined the first-order chemistry of the body and blood es. Although considerably more knowledge has been acquired from the ous examinations of the Shroud beginning in 1898, these examples illus- e how each occasion of scientific examination has increased the body of ledge concerning the Shroud. Thus, it is anticipated that such would be case in any future examination, in particular the one proposed here.

It is in this spirit and with these expectations from history, along a genuine interest in resolving basic issues associated with the ud, that STURP submits this proposal.

RIPTION OF STURP

STURP is a formal, multidisciplinary relationship between individuals are interested in performing scientific studies on the Shroud of Turin. single goal of STURP is to perform and enter those studies into the anent scientific literature of mankind for review. While everyone in P is free to have whatever religious opinion of the Shroud he or she es, the sole intent of STURP is to conduct unbiased scientific stigations of the Shroud as per classical scientific method.

The STURP relationship is based on a formal agreement which is ntarily executed by all its members. Every STURP investigator will have red into this agreement prior to any investigation of the Shroud which t be permitted. STURP believes that the multidisciplinary approach is best vehicle, by virtue of internal collaboration balanced with -interaction and internal criticism, for achieving responsible ntific inquiry regarding the Shroud. To achieve such a level of dination, given the strong public interest in the Shroud and our desire have a responsible group, an agreement understood in writing by all ers is necessary. This agreement, provided in Appendix A, covers basic es which collectively are intended to provide for responsible stigations of the Shroud and responsible reporting of those stigations. These issues are:

Membership - The first clause of the agreement defines that a member of P is anyone who has executed the basic STURP agreement form. It is rtant to recognize that STURP is not a society but a project dedicated ly to the scientific study of certain aspects of the Shroud.

Accordingly, membership is restricted to those individuals who, by virtue of special qualifications, are able to fulfill specific functions (e.g. scientific, administrative, logistic, etc.) which support directly the basic STURP mission. Accordingly, STURP must necessarily be selective in its membership, and all members are required to execute the basic STURP agreement. (It should also be noted that the membership of STURP may change according to specific requirements).

2. Duties - It is important to note that all members of STURP are volunteer and none shall be paid a salary of any kind by STURP for their research efforts. Indeed, STURP is registered in the United States as a non-profit corporation. All work is performed primarily on personal time. Thus, all members are involved because of a genuine interest in the Turin Shroud. Accordingly, in clause 2, STURP acknowledges that every member is free to proceed with his or her studies to the extent permitted by constraints of family, job, and life-style.

Thus, it should be anticipated that the proposed studies will take longer than if performed professionally as a salaried research program. However, STURP has demonstrated that, although it is composed of volunteer members, it can bring all its proposed studies to their published conclusions.

3. Copyright - The copyright clause pertains to the proper use, custodianship, and ownership of all data collected by STURP members in both the 1978 and the currently proposed testing program. STURP wishes to always be in a position to study, restudy, defend, demonstrate and evaluate scientific hypotheses. Accordingly, STURP requests of His Eminence that all data collected from the Shroud including photographic, numerical, probe measurements, and microsamples become the permanent property of both STURP and the individual investigator (the latter would act as normal custodian of the data). STURP intends that the data will be used only for academic purposes. The joint ownership of the data by STURP and the individual investigator is to guarantee to all STURP members, as well as to potential well-qualified collaborators external to STURP, access to data collected under STURP sponsorship. It will also be understood that His Eminence, as custodian of the Shroud, will have perpetual access to any STURP-owned data.

4. Confidentiality - In general, STURP wishes to conduct its studies in an atmosphere of openness and is willing to cooperate technically with other groups (or individuals) which might be allowed to examine the Shroud. Indeed, we indicate ways of cooperation below. However, STURP also recognizes its responsibility to the custodians of the Shroud, interested public, scientific community, and its own membership to insure that only responsible and accurate information about the Shroud is released in the name of STURP. Accordingly, the STURP agreement includes a requirement of confidentiality. It should be noted that confidentiality pertaining to any area of research can be removed by STURP (e.g. in order to participate with other responsible groups or individuals as discussed below), and the entire confidentiality clause expires completely after three years from the date of examination. It is not the intent of the confidentiality clause to restrict Academic Freedom (which is guaranteed in another clause of the agreement)

r to be an impediment to effective and creative research. Rather, the tent is merely to coordinate and regulate the manner in which URP-sponsored studies are placed into the public domain. In no case will URP restrict information or research progress from His Eminence, in whose re the Shroud is entrusted. Indeed, the publication record of STURP in cepted scientific journals, as provided in Appendix B, demonstrates the gh credibility with which the international scientific community has ceived past STURP work. It is noteworthy that these studies were rformed under a similar condition of confidentiality (which expired after ree years in October 1981).

Confidentiality impacts public relations and publication procedures. cordingly, it is appropriate to discuss how STURP intends to manage these blic information channels.

a. Public Relations - So as not to allow misinformation concerning STURP's research program to be disseminated to the general public, all members of STURP will be required not to speak as the official STURP spokesperson. Any member of STURP, however, is free to openly discuss personal scientific (or religious) views concerning the Shroud as long as these are not presented as coming officially from STURP or do not conflict with existing confidentiality requirements. The only member of STURP who will speak officially in the name of the group is the public relations director who serves at the pleasure of the Board of Directors of STURP. The reason for this policy is to ensure that the scientific activities of STURP are presented fairly, accurately, and responsibly to the general public and scientific community which STURP regards as the proper and rightful recipients of all STURP studies.

b. Publication - The internationally accepted and responsible format for placing scientific information into the public domain is the peer-reviewed scientific journal. It is intended that this procedure be continued by STURP. However, since STURP, is a multidisciplinary research project, each scientific paper from the STURP membership will be peer-reviewed by STURP prior to being submitted to a journal where the paper will be reviewed a second time. This review process is intended to help the author(s) achieve the highest level of scientific excellence and to bring critical issues into focus. In no case will any paper be censored by STURP (because of academic freedom); however, STURP will reserve the right not to sponsor or endorse the paper if irreconcilable differences arise. In that case, such a lack of sponsorship will be made clear in the publication; otherwise the paper will bear the name of STURP. Thus, STURP will ensure that only well-thought out studies will be published in its name so as to make a contribution to the credibility and excellence of studies regarding the Shroud.

Finally, STURP will regularly keep His Eminence and whomever he wishes informed as to the current progress of its Shroud studies, and published copies of all technical papers will be forwarded to him.

Academic Freedom - Every member of STURP is recognized as being able to sue scientific truth as he or she sees it. No one in STURP or STURP collectively will interfere with this fundamental right of all members.

However, this does not mean that, as a scientist, one does not have the responsibility of being critical of or to disagree with the conclusions of another in so far as correct scientific understanding is the goal.

STURP is managed by a seven person board of directors, all of whom are active STURP members. Elected officers consist of a president, vice president, and secretary. The educational level within STURP consists of approximately 53% Ph.D. (or M.D.),and 35% M.S. degrees, covering such diverse scientific disciplines as chemistry, biology, microbiology, physics, forensic medicine, and computer science. 53% of the STURP membership on these proposals consists of new members, thereby providing a complimentary mix of experienced and new minds. Most members are employed professionally in recognized scientific institutions including universities, national laboratories, scientific industries, and conservation/museum centers. Professional Vita information on most investigators of this proposal is supplied in Appendix C.

COLLABORATION WITH OTHER GROUPS OR INDIVIDUALS

STURP believes that scientific studies of the Shroud are best served through a balanced interaction between various Shroud research groups and individuals. These interactions, well established in the tradition of science, are characterized by collaboration and peer-review. Collaboration allows for important exchanges of information, data, and ideas. Peer-Review, on the other hand, provides for critical and independent review of another's scientific work. Without collaboration, scientific research takes on a cumbersome inertia; without peer-review the chances of error and tendency towards mediocrity in research are increased.

Accordingly, STURP wishes to collaborate, with other well-qualified Shroud groups and individuals, especially those who might be granted access to the Shroud for scientific purposes. In these interactions, STURP encourages such groups to maintain their respective identities as scientific groups so as to encourage a mutual, first level peer-review character of the scientific exchange. In particular, STURP proposes to:

(1) Make available the same examination table used in 1978 to such groups or individuals;
(2) Include full participation from such groups or individuals in on-site (in Turin) scientific discussion sessions as proposed and discussed in work package number 7 of this proposal;
(3) Include full participation of such groups or individuals in direct on-site (in Turin) chemical testing of microsamples from the Shroud, as discussed in work package 3 of this proposal;
(4) Extract microsamples for other groups as requested by them and approved by His Eminence using the special micro-manipulator tool discussed in work package 3 of this proposal;
(5) Make available (at cost) to qualified users, photographic, x-radiographic, and electronic image analysis data collected on-site for subsequent studies by these users.
(6) Participate in scientific symposia on the Shroud which might be held to include various Shroud groups or individuals.

(7) Consider well qualified persons from other groups as Coinvestigators on various work packages of this proposal (discussed in detail below).

(8) Further develop, in collaboration with other investigators, experiments that might be performed by members of STURP and/or other groups (or individuals) that are not covered in this proposal which might help to resolve remaining issues of the Shroud.

NOTE: Items (2), (3), and (5) are intended to provide each Shroud research group or individuals with a common, agreed upon set of data and analyses from which subsequent, collaborative research efforts can proceed. In order that the discussion and examination sessions provide responsible information to the general public and that the integrity of the sessions be preserved, procedures will be negotiated and mutually agreed upon in writing by all participating parties prior to the proposed examination. Participation as a Coinvestigator, proposed in item (7), will be subject to the same criteria as for the coinvestigators listed on the various work packages of this proposal, i.e. execution of the STURP agreement form (discussed previously) and concurrence of STURP and the appropriate principal investigator.

PROPOSED EXPERIMENTS AND FACILITIES REQUIREMENTS

This proposal is the product of nearly six years of intense work by members of STURP. Following the 1978 examination, STURP members met at six month intervals over a period of three years to exchange information, data, and results, as well as to critique eachother's scientific research. Representatives of other Shroud groups were invited to major workshops. During this period, papers detailing specific techniques and results were submitted and published in scientific journals. In May 1981, STURP formally presented a summary of results to His Eminence, Cardinal Archbishop Ballestrero. On May 13, 1981, STURP also was to make a similar presentation to the Pope at a brief meeting following his usual Wednesday audience in St. Peter's Square; but this was rendered impossible by the most regretable attack on the Holy Father. (Nevertheless, in October 1983, one day after the Shroud had been formally given to the Vatican, one member of STURP presented the Pope with a three-dimensional statue of the Shroud, a result of computer investigations of the Shroud image).

In October 1981, STURP made a formal public presentation of its results at a symposium held in Connecticut (to which representatives of the British Society, Turin Centro, and Roman Centro were invited; and some made presentations of their own). During the next 1½ years, STURP published summary/status papers of its investigations in Scientific journals. Since 1978, members of STURP have also made literally over 1000 invited scientific presentations to interested universities, laboratories, civic and church groups (of all denominations), scientific/engineering societies, industry, and organized Shroud groups. These Scientific Presentations have been given in many countries such as the United States, Italy (Turin and Rome), England, Portugal (to King Umberto), and Canada.

In July 1983 and again in October 1983, STURP members convened to assess the status of their previous five years of study. It was determined

that, considering the 1978 examination was only five days long, the project was successful, but in a preliminary sense. Although many scientific papers had been published by STURP, it was recognized that a responsible, conclusive report could not be issued without further examination of the Shroud by STURP. Critical, unresolved issues were first discussed and then experiments proposed which could address them. It was then decided that STURP should petition the Archbishop of Turin, custodian of the Shroud, for access to the Shroud to perform these experiments so as responsibly complete the studies begun in 1978. This proposal is the result of 13 months of preparation and consolidation of these ideas. STURP has also sought out additional investigators, many among the best in their fields, to perform the proposed program.

The STURP proposal is divided into twenty-six work packages, all of which are interrelated and address specific questions which fall into the three categories of (1) Conservation, (2) Image Formation, and (3) Authenticity. These questions are listed in Appendix D along with the work packages designed to address them.

At the head of each topic area is a principal investigator(s) who has the responsibility for overseeing his particular experiment to its published conclusion. To avoid large numbers of people and equipment involved with the Shroud at any given time during the examination period, STURP proposes to use a phased examination procedure whereby only a minimum number of persons and equipment will be directly present with the Shroud at any given time. To accomplish the examinations in a minimum amount of time, STURP proposes to order all direct studies in a sequential, twenty-four hour, round the clock program. For purposes of illustration, a tentative schedule is provided in Appendix E which shows how the STURP program could be accomplished in a three week time period. This schedule can be adapted so as to be compatible with examinations of other groups or individuals, as was the case in the 1978 examination.

We request that the size of the test room be large enough that the Shroud can be easily photographed in its entirety from a single position. It is also requested that, if possible, the room have no windows, have access to electrical power (to be specified) and running water with sink to accommodate a portable darkroom and chemical testing facility. It would be advantageous if adjacent, smaller rooms could be provided (as in 1978) for equipment and experiment preparation. All investigators will ensure that no damage occurs to the rooms and, of course, to the Shroud itself. However, some of the investigations require a small quantity of samples to be extracted from the Shroud in order to perform the requested studies. The complete sample requirements associated with this proposal is provided in Appendix F. In Appendix G, we list the resources that would be generated as a result of the proposed investigations; these could be made available (at cost) to all qualified investigators.

The specific examinations (discussed in detail below) are as follows:

1. Artificial Aging of the Shroud by On-Site Low Power Laser Irradiation - Jackson, Ph.D.; Adler, Ph.D.; Arthurs, Ph.D.; Gilbert, Ph.D.; Sega, Ph.D.; Lukasik, Ph.D.; Long; Stappaerts, Ph.D.; Druzik, Ph.D.

2. Chronological Order Determination of the Blood and Image Applications - Schwalbe, Ph.D. and Druzik.

3. Collection of Materials from the Surface of the Turin Shroud for Chemical and Physical Testing - Adler, Ph.D. and McNeil, Ph.D.

4. Conservation Testing on the Shroud of Turin - A - Druzik; McLean; Kajitani; Hutchins; Hersh, Ph.D.; Heller, M.D.

5. Conservation Testing on the Shroud of Turin - B - Druzik; Schwalbe, Ph.D.; and Jackson, Ph.D.

6. Dating the Shroud of Turin Using Radiocarbon Analysis - Dinegar, Ph.D.; Harbottle, Ph.D.; Oeschger, Ph.D.; Damon, Ph.D.; Tite, Ph.D.; Stuiver, Ph.D.; Otlet, Ph.D.; Hall, Ph.D.; Gove, Ph.D.; Coleman, Ph.D.; Donahue, Ph.D.

7. Discussion Sessions and Microscopic Examinations - Jumper, Ph.D.

8. Electronic On Site Data Capture for Image Processing of the Turin Shroud - Schumacher; Jackson, Ph.D.; Miller; Lynn; Avis.

9. Foldmark Examination on the Turin Shroud - Jackson, Ph.D.; Miller; Druzik; Hutchinson; Wilson.

10. Forensic Wound Reconstruction and Examination of Trace Evidence on the Shroud of Turin - Bucklin, M.D. and Inman.

11. Infrared Investigation of the Turin Shroud - Ercoline; Johnson; Modisette; Sega, Ph.D.; Jackson, Ph.D.

12. Isotope Ratio Measurements of Oxygen and Hydrogen from the Cellulose of the Shroud Fabric - DeNiro, Ph.D.; Druzik; Schwalbe, Ph.D.

13. Large Format Color Photography and Video Documentation - Miller; Johnson; Schwortz.

14. Microbiological Analysis of Iron Oxide Deposits on the Shroud of Turin - Cairney, Ph.D.

15. Microbiological Analysis for On-Site Conservation Studies of the Turin Shroud - Cairney, Ph.D.

16. Microfauna and Microflora Identification on the Shroud of Turin - Riggi; Porrati; Mastropirro; Saverio.

17. Particle Analysis from the Foot Region and Bottom of the Shroud - Heller, M.D.

18. Penetration Depth Measurement of the Body Image into the Shroud - Jackson, Ph.D.; Gilbert, Ph.D.; Miller.

19. Photographic and Image Analysis Study - Schwalbe, Ph.D.; Johnson; Miller.

20. Radiography of the Turin Shroud at Low Energies - Mottern; Druzik; Airth-Kindree; Sisson; Sample; London.

21. Scientific Photography - Miller and Pellicori.

22. Scorch Experiment - Schwalbe, Ph.D. and Druzik.

23. Spectroscopy, UV Through IR on the Turin Shroud - McNeil, Ph.D.; Adler, Ph.D.; Pellicori; Gilbert, Ph.D.; Arthurs, Ph.D.

24. X-Ray Diffraction Analysis - Jenkins, Ph.D. and Schwalbe, Ph.D.

25. X-Ray Fluorescence - A - Schwalbe, Ph.D.; Jenkins, Ph.D.; Riggi.

26. X-Ray Fluorescence - B - Carter, Ph.D.; Jumper, Ph.D.; and Carriveau, Ph.D.

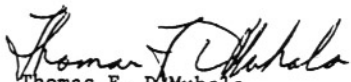
CONCLUDING REMARKS

Thus, the program we propose covers many areas of current scientific interest. We believe these studies have the capability of providing definitive answers to questions which would otherwise lie unanswered. We further believe that STURP has demonstrated a capability of bringing scientific studies to their published conclusions in accepted scientific literature. As a group, we have amassed a large resource of expertise on the Shroud which we would bring to bear upon the complex scientific issues as they are presently understood. Accordingly, we ask that written permission to perform the studies be granted at the earliest opportunity so that we might be able to pursue those Shroud studies which we believe are of interest to the world and the custodians of the Shroud.

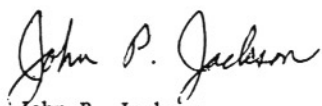
Finally, we request the pleasure of an audience with His Eminence and designated scientific advisors in matters of the Shroud so as to discuss and answer questions concerning this proposal. We ask that this occur on or before March 1985.

Respectfully submitted
August 15, 1984

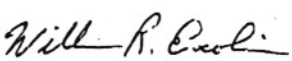
On behalf of the Board of Directors,
Shroud of Turin Research Project, Inc.



Thomas F. D'Muhala
President, STURP



John P. Jackson
Vice President, STURP



William R. Ercoline
Secretary, STURP

ARTIFICIAL AGING OF THE SHROUD Y ON-SITE LOW POWER LASER IRRADIATION

PRINCIPAL INVESTIGATOR: J. P. Jackson, Ph.D.
Kaman Sciences Corporation

COINVESTIGATORS: A. D. Adler, Ph.D.
Western Connecticut State University

E. Arthurs, Ph.D.
R. Gilbert, Ph.D.
Oriel Corporation

R. M. Sega, Ph.D.
University of Colorado at Colorado Springs

S. J. Lukasik, Ph.D.,
W. H. Long, Jr.
E. A. Stappaerts, Ph.D.
Northrop Corporation

J. R. Druzik
Los Angeles County Museum of Art

I. OBJECTIVE

To measure the rate at which the Shroud background cloth discolors with time at (1) elevated temperatures and (2) short UV wavelengths capable of photolytic degradation. These measurements will provide benchmark characterizations for laboratory conservation and image analysis studies of how the Shroud cloth can be expected to degrade under various environmental conditions.

II. STATEMENT OF THE PROBLEM

Reflectance comparisons of the Shroud with new linen by Pellicori [1] indicates that the Shroud cloth has suffered some degradation; hence it appears yellowed in reflectance color photographs [2]. In addition, the body image and faint scorch areas appear to be regions of cellulose degradation, but in a more advanced state [3]. Stated simply, the Shroud linen appears to be in varying stages of degradation such that what we know as the body image and scorch regions are visible as recognizable yellow-brown patterns upon a more lightly yellowed cloth background.

Thus, cellulose degradation seems to represent the basic chemistry of important visible features on the Shroud. Accordingly, it is proposed that measurements be made to characterize how rapidly the Shroud cellulose degrades under scientifically controlled conditions. This information would benefit most directly conservation issues since extrapolations as to future degradation of the visible image on the Shroud relative to the cloth background could be made. In addition, such aging data should impact

questions as to (1) has the body image always been visible or did it develop with time against a slower developing cloth background, (2) how long would it take the Shroud background to reach its present state of discoloration if it is assumed that this occurred at ambient temperature (or some specified conditions), (3) what was the relative effect of the 1532 fire with respect to natural aging discoloration, (4) what further degradation effects might be expected on the Shroud, and (5) what was the effect of the 1532 fire upon the body image?

Two types of cellulose degradation are considered in this work package, thermal and photolytic. In the first, degradation reactions occur as a result of natural thermal motions of molecules. At room temperature, the reactions are very slow but at elevated temperatures occur rapidly. This phenomenon forms the basis of standard artificial aging experiments; cellulose degradation rates are measured at elevated temperatures (for short times) and then used to extrapolate degradation behavior at lower temperatures (for longer times) [4-5]. However, in such studies, care must be used not to oversimplify the generally complex and coupled degradation reactions [5]. In the second, ultraviolet radiation, which has photon energies large enough to directly rupture chemical bonds, can induce cellulose degradation. Such wavelengths are found for example in the Solar spectrum and it is known that the Shroud has been exposed in daylight as recently as 1933. In addition, some have proposed radiation as an image formation mechanism. Accordingly, to supply data for conservation and image formation studies, we propose a limited study to measure the response of the Shroud to ultraviolet radiation.

III. METHODS AND MATERIALS

A. Thermal Aging

To determine the rate of degradation of the Shroud cellulose with temperature, we propose to heat several small spots on the Shroud with a low power laser and observe how the reflectivity, a measure of cellulose degradation, changes with time and temperature.

The laser flux, S, required can be estimated from the relation,

$$S = \frac{2\sigma e}{a}(T^4 - T_o^4) + \frac{2h}{a}(T-T_o)^{5/4} \qquad (1)$$

where T is the ambient (room) temperature of the Shroud, T the desired experimental temperature, a the laser/cloth coupling coefficient, the cloth thermal emissivity, and h a heat conduction/convection parameter into air ($h=4.24\times10^{-5}$ cgs units [6]). Equation (1) expresses the steady state energy balance between the net heat loss mechanisms of thermal radiation (first term) and heat conduction/convection into the surrounding air (second term).

The factor of two accounts for heat exchange on both sides of the cloth (assuming panels of test frame removed).

The laser wavelength is chosen to match the peak of the blackbody spectrum, λ_{max}, at ambient temperature which, by Wien's standard formula,

$$\lambda_{max} = \frac{2.9 \times 10^3 \ \mu K}{T} , \qquad (2)$$

is 9.8 microns at 293 K (20°C). Thus, a CO_2 laser operating at 10.6 microns will be used. The photon energies at such wavelengths (0.11 eV) are considerably lower than the roughly 3.7 eV required for photolytic rupture of cellulose molecular bonds [5].

The laser radiation will be applied over several one centimeter diameter spots in a relatively unimportant part of the Shroud (see Appendix F). The laser flux will be adjusted so that the cloth temperature is approximately 150°C which Pellicori has shown discolors linen to the intensity of the Shroud image in 7.5 hours [1]. Since, at this temperature, the emitted thermal radiation (roughly 6.9 microns by Equation 2) and the laser radiation are both in the infrared, the ratio e/a in Equation (1) is taken to be unity. Measurement by the principal investigator indicates that e=0.86. Hence, by Equation (1) the estimated laser flux for the experiment is about 0.5 watts/cm^2.

Thus, it is proposed that a 10.6 micron, CO_2 laser of adjustable power ranging from zero to several watts (output power) be used to irradiate selected small one centimeter diameter spots. The temperature will be monitored by an infrared thermography system capable of digitally recording thermal images of the heated spots to an accuracy of 0.1°C, as discussed in another work package [8]. A similar procedure was demonstrated by Accetta in 1978 to obtain IR thermographic images of the Shroud upon irradiation of the Shroud by a lamp [9]. Reflectivity and UV fluorescence will be measured as described in another work package [10], over a continuous 400-700 nm wavelength interval (when the laser is momentarily turned off) at various times during irradiation. Changes in reflectivity will be recorded as a function of time at the measured temperature which will be held constant by the laser. The maximum reflectivity change during the experiment will be held to twice the dynamic range of the facial body image, 7% at 550 nm [11]. Thus, the permanent discoloration intensity change received by the Shroud will be small. Since discoloration follows a logarithmic time dependence on temperature [4], it is proposed that five spots be irradiated in open air so as to obtain increments in discoloration time (i.e., 22s, 216s, 36 min, 6 hours, 60 hours), covering four orders of magnitude. In addition, it is proposed that three spots be irradiated in an oxygen free environment for logarithmically different times (to be determined by experiment) so as to characterize thermal degradation in the absence of oxygen. This will be accomplished by placing two plates on either side of the Shroud and purging the interior space with nitrogen. Holes in the plates will allow for laser irradiation and IR inspection. Thus, measurements with and without oxygen will bracket the storage conditions in which the Shroud is maintained (presently in a rolled configuration). In addition, x-ray fluorescence [12] will document the elemental composition of the experimental spots since it is possible that certain inorganics may affect the aging rate. These experiments will provide a data base from which to extrapolate over comparable orders of magnitude (i.e., thousands of years) reflectivity changes at longer time intervals at specified temperature and oxygen

conditions. To obtain the long exposure times, it is not necessary to perform the experiment continuously in one block of time. The degradation process is cumulative and therefore the required exposure times can be achieved in intervals compatible with other work packages of this proposal.

Similar measurements will be performed away from the Shroud on similar linen. On these samples, relative humidity, oxygen content, elemental composition, and temperature will be varied and standardized to the measured reflectivity response curves measured for the Shroud. In this way, the Shroud data will serve as benchmark calibration measurements for laboratory studies relating to the basic aging rate questions posed above in Section II.

In addition to serving as a laboratory standard for subsequent laboratory artificial aging studies, the reflectivity measurements made on various regions of the Shroud (e.g. body image, cloth background, and 1532 scorch regions) by other investigators of this proposal set [10], are directly comparable (since they are made concurrently in the same experimental configuration) with high accuracy to the controlled discolorations proposed herein. Accordingly, important conservation and time-dependent body image discoloration information can be obtained. However, the disadvantage of this laser procedure, which is nature's price for relinquishing time-dependent discoloration information, are permanent discoloration spots on the Shroud. However, unlike standard artificial aging experiments, no samples are required to be removed from th e Shroud. None of the measurements will be made on the body image and only in relatively unimportant parts of the Shroud (perhaps that part of the Shroud under the blue border fabric attached to it). Compared to the massive scorches already on the Shroud, these discolorations represent a very small perturbation. Further, the discolorations, being made under controlled conditions, will be no darker than twice that of the faint body image and accordingly not nearly as dark as most of the visible 1532 fire damage.

Finally, precautionary shielding (e.g. shielding curtains and clear plastic glasses), consistent with American and Italian regulations, will be used to protect personnel from infrared eye damage.

B. Photolytic Aging

In thermal aging (above), laser photons are absorbed as heat which increases the rate of cellulose degradation reactions. However, if the photons are sufficiently energetic, direct rupture of molecular bonds is possible. The required energy is on the order of 80 to 90 kcal/mole [5] corresponding to about 3.7 eV/bond. This amount of energy is contained in photons of wavelengths less than about 330 nm. Such wavelengths are characteristic of excimer lasers, in particular the krypton Floride (KrF) laser which radiates at 248 nm or argon Floride (ArF) at 193 nm. According to Hon [7], both wavelengths can photodissociate cellulose C-C, C-O, C-H, and O-H bonds, since the minimum threshold for photolytic rupture of these bonds is about 275 nm.

It has been observed that significant degradation occurs when cellulose is irradiated in sunlight with an accumulated fluence per wavelength, E_λ, of about 1.8 $J/cm^2\text{Å}$ [5]. Thus, for a flux, S, irradiation time, t, and laser bandwidth, $d\lambda$, the relation

$$S = \frac{E_\lambda \cdot d_\lambda}{t} \qquad (3)$$

must be satisfied in order to induce significant cellulose degradation.

This equation, however, is not valid for all laser fluxes because some fraction of S might be absorbed as heat rather than as ruptured bonds. As discussed above, heat is also capable of aging cellulose and, if S is high enough, could mask degradation due to photolysis. Thus, we must require that S be sufficiently low that thermal effects will not be significant. We can ensure this by requiring that $T-T_o$ be less than about 10 K (which probably causes cellulose aging to occur on century time scales). More specifically, Hon [7] reports no evidence of a temperature coefficient of yellowing associated with UV irradiation with a ten degree temperature differential around room temperature. According to Equation (1), a ten degree temperature difference restricts the flux to (e=.86, a=1.0)

$$S < 1.7 \times 10^{-2} \text{ watts/cm}^2, \qquad (4)$$

(if we conservatively assume that all laser flux is absorbed as heat.). Thus, if we take S to be 10 mwatts/cm^2, we calculate an irradiation time (via Equation (3)) of 540 seconds (9 minutes), assuming a typical 3 Angstrom bandwidth, $d\lambda$, for a KrF laser.

Thus, it is proposed that one spot of one centimeter diameter on the Shroud be subjected to KrF or ArF laser radiation of approximately 10 mwatts/cm^2 (output power density) for about ten minutes (The actual time will be determined experimentally in the laboratory prior to examination.) As with the above thermal aging experiments, reflectivity as a function of time and temperature will be monitored by remote sensing [10]. The required temperature condition will be determined by monitoring temperature with the thermographic system.

This experiment will serve as an important benchmark for determining how the Shroud ages under photolytic degradation and, like the thermal aging data, will be used as a standard to normalize subsequent laboratory linen experiments performed under varying experimental conditions.

We finally note that the thermal and photolytic discolorations, being accurately characterized spectrally, can serve as a baseline for tracing degradation of the Shroud by future generations.

IV. EQUIPMENT

1. Variable power 0-10 watt (average output power) (15 lb) California Laser CO_2 laser
2. Variable power 0-100 m watt (average output power) Quanta Ray EXC401 (220 lb) pulsed 0.1 J, 1-100Hz KrF/ArF laser
3. Oriel Corporation custom Reflectometer
4. IR Thermovision (AGA-780) with digital image recording capabilities (via OSCAR System)
5. Plastic eye glasses
6. Screens
7. Inert gas irradiation chamber (to be constructed)
8. X-Ray Fluorescence spectrometer
9. Oxygen-free radiation cell

V. TIME REQUIRED

A. Setup in Turin 12 hours

B. On Shroud 90 hours

(includes reflectivity and temperature measurements, and can be performed concurrent with other long-duration experiments such as x-ray fluorescence or during experiments where no conflict is presented)

C. Post Shroud 2 hours

D. At home 5000 hours

(includes reconfiguration long-duration aging experiments and analyses)

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CHRONOLOGICAL ORDER DETERMINATION OF THE BLOOD AND IMAGE APPLICATIONS

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COINVESTIGATOR: J. R. Druzik
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I. OBJECTIVE

We propose to remove a total number of about 20 serum-coated fibrils primarily from the clear areas at the blood margins. The fibril samples will be treated with a protease-enzyme to remove their coatings, and their exposed surfaces will be examined with both optical and electron microscopy. A study of the surface structure of the fibrils should reveal whether the blood or the image arrived first on the cloth. This determination bears strongly on the question of the origin of the Shroud, whether it was an actual burial cloth or the product of human artistry.

II. STATEMENT OF THE PROBLEM

There is sharply divided opinion on the question of the origin of the Shroud. Some think the image is most likely the product of human artistry. Others believe it was an actual burial cloth and the image resulted in some way by contact with (or proximity to) a human corpse. The problem is that no definitive test has been proposed to distinguish between the two possibilities. In this connection, the identification of the "blood"-stain composition as blood [1,2] stands as rather ambiguous evidence, since it is possible that an artist might have used human blood to create the blood stain regions. And yet, as one of the conclusions of the research carried out thus far, we feel this finding may be one of the most significant, particularly if it can be determined whether the blood or the body image arrived first on the cloth [3].

If the Shroud had been used in a burial, we would expect the blood stains to have been transferred first, perhaps upon immediate contact with a body. The image, however it formed, would have followed. On the other hand, if the image were the work of an artist, we would expect it to have been applied initially and the blood stains to have followed only after their intended locations had been established. We think one goal of the proposed research program should be to establish the chronological order of the blood and body image applications. A unique determination will not stand as definitive evidence because there are, no doubt, alternative scenarios to those considered here. However, none of the alternatives suggested thus far have seemed highly plausible. The order of the blood and body image applications, therefore, remains an important question.

II. METHODS AND MATERIALS

Schwalbe and Rogers [3] identified the clear blood margins as potentially the most significant points of interest regarding the order of the blood/image application. We suggest that a coordinated series of tests be conducted in these areas to determine their nature more exactly. Some

preliminary work has already been done [2,4]. Heller and Adler [2] obtained positive tests for protein, including albumin specifically, from sticky-tape samples of these areas. Their results suggest that blood serum is present.

If this is true, a possible explanation is that the clear visual appearance of the base material and its fluorescent properties were preserved as the serum inhibited the formation of image (which is nonfluorescent [5]). We can test this hypothesis by sampling fibrils from the halo areas. The fibrils, after removal, would first be stripped of their coatings and their surface structure examined. If serum-covered linen had been "protected" from the image-forming process, we would expect to see non-yellowed and smooth surfaces similar to and perhaps even less degraded than those characteristic of the nonimage areas. If the image had been formed before the blood was applied, we should see some of the fiber surfaces corroded as Heller and Adler [2] described the microscopic appearance of yellow image fibers under phase-contrast.

A total of about 20 serum-coated fibrils from both blood-stain and clear margin areas should be sufficient for this study. Adler and McNeil [6] will collect the samples with micromanipulators. As the fibrils are removed, each will immediately be sealed in an individual glass capillary. Subsequent preparation and examination of the materials will be carried out in our own laboratories (Los Alamos National Laboratory, Los Angeles County Museum of Art Conservation Center, and Western Connecticut State University). Removal of the protein will be accomplished with the protease-enzyme treatment as previously used by Heller and Adler [2]. The fibril surfaces will then be examined both by Nomarski phase-contrast and scanning electron microscopy. Further elemental analyses of blood artifacts will be carried out on the particle-induced x-ray emission (PIXIE) system at the Crocker Radiation Laboratories at the University of California Davis campus.

IV. EQUIPMENT

Only the first phase of this work, the sample collection, will be undertaken on site in Turin. For this we will require the aid of Adler and McNeil microsample removal techniques [6].

V. TIME REQUIRED

A.	Pre-Shroud in Turin:	2 hours
B.	On-Shroud in Turin:	6 hours
C.	Post-Shroud in Turin:	2 hours
D.	At home:	100 hours

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COLLECTION OF MATERIALS FROM THE SURFACE OF THE TURIN SHROUD FOR CHEMICAL AND PHYSICAL TESTING

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COINVESTIGATORS: (Cited in the individual proposed studies given below)

I. OBJECTIVE

The major objective is to confirm, further test, and extend the previous investigations performed on the Shroud of Turin and the various hypotheses that have been suggested with respect to its origin and nature. This will be accomplished via the collection of micromaterials from the Shroud followed by specific chemical and physical testing in the subject areas of (1) confirmation of previous chemical tests, (2) provenance studies, (3) forensic studies; (4) conservation studies; and (5) image formation hypothesis testing.

II. STATEMENT OF THE PROBLEM

Beginning with Pia's discovery of the "reversed image" character of the Shroud [1], there have been numerous scientific and forensic studies of the Turin Shroud. These have been summarized and reviewed extensively [1-18]. While spectroscopic, microscopic, and photographic studies have contributed greatly to our understanding of the phenomena that constitute the Shroud of Turin, the chemical and physical studies on the materials collected from the surface of the cloth have been of equal importance in elucidating matters of interest, establishing the consistency of the spectral data, and identifying the presence or absence of specific chemical species of importance with respect to various proposed hypotheses [13, 14, 18].

However, the amounts of material taken in the past for these purposes were limited, the samples were usually collected in a general way without specific "targets" in mind (as one did not really know what to expect), and subsequently experimental problems were encountered in dealing with the collected material in terms of adventitious debris and translocated material [13-18].

If one wishes to confirm and extend such previous studies, an investigation must be made of the various ways material can be collected from the surface of the Turin Shroud and those techniques must be chosen that will be best suited to the needs of the experimenter in view of the limitations imposed by time, man-power, equipment, costs, requirements of

conservation of the relic itself, and amounts and kinds of material necessary to test the proposed hypotheses of interest.

Some specific questions, for example, are: (1) are the blood images definitely human blood, (2) are there materials on the cloth (e.g., dirt, pollens) that can locate it at various times in various places, (3) are there materials present that can further confirm the forensic hypothesis that the cloth did, in fact, once enshroud a wounded human body, (4) can any of the various proposed image hypothesis mechanisms (e.g., scorch, ionization, photo, chemical, etc.) be tested, (5) are there artists' materials present and can they be accounted for, and (6) can novel materials be discovered that in themselves suggest new ideas concerning the nature of the Turin Shroud.

III. METHODS AND MATERIALS

A number of proven archeological and forensic methods have been established for the collection of materials from a cloth surface for subsequent chemical and physical testing [19-26]. Amongst these are three macro-methods (direct excission with tweezers and cutters, "sticky tape" sampling, and "wide-area" vacuum filtration) and two micro-methods (excission with micromanipulator techniques and air-pipeting under low power microscopic observation).

The macro-methods have been employed in previous work on the Shroud: excission in the 1973 testing [7], "sticky tape" sampling by Frei (who invented the technique [26]) and Rogers/Dineger [13-15], and "wide-area" vacuum filtration by Riggi [18]. While these techniques are all quick, cheap, easy, and convenient, they have the disadvantage of being relatively non-specific, especially the latter two methods. One gets "everything" in the area sampled - including adventitious debris and translocated materials along with the desired sample of interest [14,18]. Further, they all have the potential of damaging the cloth and degrading its integrity from the viewpoint of conservation and preservation. Hence, great care has always been employed in all previous studies to do such sampling properly and sparingly (e.g., the use of a controlled pressure tape applicator) [13-15,18]. The tape method has the further disadvantage that materials of interest usually must be mechanically and chemically manipulated from the tape and adhesive before any specific testing [14]. This is time consuming and does introduce possible sources of error (e.g., oxidizing impurities in the adhesive) [14].

Alternatively, the micro-methods have the advantage of specificity, providing materials for testing free of any prior chemical "removal" procedures, and produce the least potential for damage to the integrity of the cloth. However, they have the disadvantage of being very time consuming. The air-pipet method has been recommended by the conservation experts consulted as a suitable procedure for "cleaning" the relic prior to other preservation procedures. However, more flexibility in manipulation and mode of collection is offered by the use of micromanipulator techniques (e.g., to "tease out" a length of a specific fibril of a thread). They both offer relative advantages for our studies and could be used simultaneously by several "collectors" depending on particular circumstances. In many cases, these techniques can also be used on areas of the cloth not under test while other kinds of testing are being performed. As the time required

for collection will be extensive, this is a favorable characteristic. With due consideration, therefore, we feel the two micro-methods in conjunction with a forensically acceptable documentation and collection procedure should be the method of choice in further sampling of the Turin Shroud.

The materials collected by these techniques will be employed in a variety of experiments suggested by other investigators (including those external to the STURP Proposal) to test novel hypotheses or to confirm previous ones. These proposed studies fall into several categories:

A) Confirmation of Previous Chemical Tests:

Previous STURP work established that the blood images were blood, that the body image contained no protein, that iron oxide was mainly in the water-stain margins, that all fibrils contained covalently bound Ca and Fe, that the body image chromophore was a conjugated carbonyl, and that protease treated blood image fibrils resembled non-image area fibrils suggesting that the blood images went onto the cloth before the body image process took place [13,14]. As these key findings rule against a painting hypothesis and explain many other findings on the Shroud, the tests yielding these results are of such importance that they should be confirmed by their repetition by several independent investigators. It is therefore proposed that Adler, Druzik (Los Angeles County Museum of Art, Conservation Center, Los Angeles, CA), Carter (Eastern Michigan University, Chemistry Department, Ypsilanti, MI), two to three Italian investigators (to be selected by the Italians) as well as representatives of other examination teams that might be given permission to study the Shroud jointly extract fibrils and microparticles so as to repeat these key tests on freshly documented specific materials, either on-site or in a nearby laboratory in Turin, utilizing previously established procedures [14]. The chemicals for this work are available (Adler) and could be carried through customs or mailed in advance to one of the selected Italian collaborators who can supply the needed small glassware, etc.

B) Provenance Studies:

The goal of these studies is to attempt to locate where the Shroud has been geographically and/or when in time. Several of these are presented in separate work packages [19,20]. Assistance in the collecting of these samples will be provided. Other proposed investigations are dependent on whether appropriate materials can be found and collected. For example, mineralogical, elemental, and isotopic analyses of materials such as dirt have been utilized previously for archeometric geolocation analysis, as such compositions are frequently typical for given areas [21-23]. Investigations contingent on finding such dirt have been proposed by Schwalbe and others [24,25], scanning Auger [26] (McNeil and

Adler), novel combined mass spectrometric techniques [27,28] (Heller), and by nuclear microprobe [29]. Numerous controls and contact with other previous investigators in these fields would be required for proper assessment of such data. If any of the wax samples on the Shroud contain pollens internally, Heller has also suggested these be palinologically investigated to extend and check Frei's previous pollen work [7,30,31]. Heller has corresponded with several pollen experts, soliciting their collaboration.

Forensic Studies [32-36]:

The goal of these studies is to confirm and extend previous investigations that are consistent with the Shroud having actually enfolded a human wounded body [1-18,37-43]. With the exception of one dissenting study [15], these previous studies are in general agreement that the accumulated evidence [14,18] is consistent with the blood images being blood. Two immunochemical studies [18,39] further support the hypothesis that it is most probably human blood. Unfortunately, the cross-serological reactivity of other primate bloods restricts this conclusion to probability [18]. Similarly, the forensic [2,10,38,40] and image analysis [18,41,42] studies are consistent with the hypothesis that the Shroud enfolded a wounded human body. Several further immunochemical [32,44], chemical [45-47], electrochemical [48], and chromatographic [49] studies would corroborate and extend these conclusions. A colloborative effort by Adler/McNeil and Bucklin/Inman [50], Maskel (Western Connecticut State University, Biology Department, Danbury, CT), Lavoie (West Roxbury, MA), Goldstein (Harvard Medical School, Department of Microbiology and Mol. Genetics, Boston, MA), and Higgins (Northeastern University, Department of Forensic Science, Boston, MA) will investigate such possibilities with "blood" samples collected from the Shroud.

The samples will have to first be solubilized [14,32], microspectra taken [28,43], and then subjected to HPLC [28,49] (high performance liquid chromatography) and electrophoretic [32,44] separations and then immunochemically tested [32,44] for several characteristic species (see also Proposal by Bucklin and Inman [50]). In particular, a positive immunochemical test for human HLA (histocompatability) antigens would make the identification of the blood as human far more definite [32]. Similarly, Lavoie has suggested that human lung proteins should be detectable in the lance wound and back blood images; also, that the extent of fibrinogen degradation (as seen in the HPLC and immunoelectrophoretic patterns) should be more pronounced in these areas compared with the head, wrist, and foot wound flows, as the former represents post-mortem blood and the latter pre-mortem blood [47]. Lavoie has also suggested that scourge wound samples be checked for chemical evidence of

adipose tissue (i.e., fats) [45-47]. Separation of bile pigments by HPLC would also corroborate previous work [14]. Heller has also requested that white blood cells be sought for extraction of their DNA and possible corroboration of the immunochemical work by modern nucleic acid technology [51]. Heller has obtained agreement for collaboration from several Yale staff members, contingent on finding such material. Heller is also interested in the possibility of detecting other materials indicative of violent death in selected areas of the image (e.g., specific nitrogenous compounds, such as indoles) [45-47].

D) Conservation Studies:

The objective of these studies is to obtain chemical and physical information concerning the present status of the cloth necessary for suggesting appropriate preservation procedures (cf. Druzik, et. al. proposal [52]). In this connection, several of us (Schwalbe, Jackson, Druzik, Adler, McNeil) have suggested that thermomechanical studies [28] of Shroud fibers be also considered, if appropriate samples can be located for removal, as this information would also be important to conservation considerations (cf. Schwalbe and Druzik proposal [53]).

E) Image Formation Hypothesis Testing:

The objective of these studies is to carry out experiments that exclude or permit various proposed mechanisms of formation of the Shroud image. Druzik and Schwalbe [53] and Jackson et. al. [54] have proposed further tests on the "scorch" hypothesis [13,14,41]. An HPLC pattern analysis for pyrolytic compounds (e.g., furfurals) seen in various organic solvent extracts of scorch vs. image fibrils could also further check this hypothesis and test some of Pellicori's postulated mechanisms [13,14,16,18]. The HPLC study could be included in the previous chromatographic work (McNeil, Adler).

Artists' pigments have been seen in Shroud samples [13-15]. Although McCrone has considered this as evidence that an artist painted the Shroud image [15], STURP investigators have considered this as adventitious debris from artists who have made reproductions of the Shroud [3,14,18]. Wilson has pointed out that such "reproducers" frequently contacted their facsimile with the original to sanctify the copies, thereby contaminating the original [55]. Recently, such evidences of copy/contact have been documented by Fossati [56]. Locating, analyzing [14,57], and correlating such materials to known "contacted" images would corroborate the STURP position that such materials are adventitious. This study would be carried out by Adler, McNeil, Druzik, and Carter, in collaboration, using chemical testing, micro- spectrophotometry, and HPLC techniques [14,49,57].

Recently Carter proposed an x-ray image formation mechanism [58]. The proposed x-ray studies [24,25] will test some aspects of this mechanism, but these will have to be confirmed by some specific quantitative concentration analyses for such elements as Ca and Fe in specific fibrils selected from specific areas of varying image density. Samples can be collected for electron microprobe or activation analysis [28] as suggested by Carter.

A number of proposed mechanisms for formation of the Shroud image have required ionizing radiation as part of the process [13,14,18,41]. If the cloth has been subjected to such radiation then the cellulose structure will contain internal "trapped" free radicals [59,60]. Such free radicals will produce g = 2.000 signal in ESR (electron spin resonance) spectroscopy [28] and are readily distinguishable from the paramagnetic hemeproteins [61], also present. By comparing image and non-image fibrils by EPR, the probability of an ionizing process contributing to image formation can be assessed. This will be done in collaboration by Adler and Peisach. (Einstein College of Medicine, Department of Pharmacology, Brownx, New York).

IV. EQUIPMENT

Stands, scopes, tools, chemicals, laboratory equipment, micromanipulator, etc., will be required at Turin and thus must be transported to Turin. All but the "chemical reconfirmation" tests (in Turin) will be carried out in the United States.

V. TIME REQUIRED

A.	Pre-Shroud in Turin:	1-2 hours
B.	On-Shroud in Turin:	Constant, in combination with other experiments as feasible (50 hours)
C.	Post-Shroud in Turin:	4 hours
D.	At home:	1-1½ years

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CONSERVATION TESTING ON THE SHROUD OF TURIN - A

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I. OBJECTIVE

We propose to conduct a series of examinations intended to:

(1) determine the current physical condition of the Shroud of Turin,

(2) determine the long-range suitability of existing storage and handling procedures,

(3) determine the probable method of manufacture,

(4) survey damaging environmental factors in Turin and within the cathedral of Saint John the Baptist itself (A plan will be designed for the long-term monitoring of the environment),

(5) draw up a set of criteria will which will set basic standards of storage and exhibition for the Shroud based on guidelines that have evolved over the years through some of the efforts of the American Institute of Conservation (AIC), International Institute of Conservation (IIC) and UNESCO.

II. STATEMENT OF THE PROBLEM

The practice of conservation is a multi-disciplined profession whose primary goal is the preservation of cultural properties. The steps taken to reach this goal include examination, treatment, and recommendations for display and storage.

A. Examination of Physical Characteristics

In order to establish a firm base, the following physical characteristics will be determined:

1) pH determination. The Shroud is principally composed of linen which is 70-80% cellulose [1]. Cellulose is strongly degraded by acidity even at relatively low levels of activity [2-5]. When the storage conditions do not permit the diffusion of degradation products to the atmosphere, this degradation process is often autocatalytic. It is generally assumed that in these conditions intermediate radicals are formed that further react with other intermediates or with undegraded cellulose. This causes brittleness and yellowing. In the case of the Shroud of Turin, further yellowing could be damaging to the image since it would result in a loss of contrast and possibly a loss of the entire image. Since these oxygen-independent degradation processes are acidic, a pH determination of the Shroud will be made.

2) Fiber identification and mixed fiber estimates. Previous sampling of the Shroud with sticky tape in 1978 revealed that in addition to linen, unknown quantities of cotton, silk and wool are present [6]. However, several textile conservators in our group have felt that quantitative fiber identification and mixed fiber inclusions are currently vague [7]. These results will be clarified mostly through observations with a 10-40X magnification stereo-binocular microscope [4,8].

3) Tensile strength. The loss of tensile strength is an end product of both acidic hydrolysis reactions and oxygen-dependent reactions between cellulose and oxygen, ozone or other atmospheric oxidants such as nitrogen dioxide [4,5]. We would like to artificially age modern linen samples and observe the loss of tensile strength of individual threads as a function of aging time at 100 degrees centigrade [9]. The physical measurement of minimum and maximum thread diameters on the Shroud linen will aid in selecting suitable modern linens for this test. Threads taken from margin areas of the Shroud [10] could then be tested on a tensile testor [11] and approximately located on a linear regression line for the aged modern linens. Then the modern linen samples would be tested for fold endurance and rupture. These results will be used to determine the safety of current handling and storage procedures [12].

4) Old mends. X-ray examination of the old repairs indicates that, while the repair as a whole seems to be serving its purpose, there are many areas in which patches appear to be pulling away and might be causing damage at the present time. Some of the repairs are crude and may not be needed. Since the twist direction and number of twists per unit of length of the mending threads are not known, it is not possible to gage if the forces of expansion and contraction from relative humidity are pulling adversely between patches [13-16], mending threads, and the Shroud linen itself. Twist will also play a role along with weave when considering purely mechanical movement. Transverse compression, longitudinal extension and compression, torsion, bending, and frictional restraint are a few types of fiber deformation. With x-ray alone it is not possible to determine these

relationships, nor can the areas of extreme pyrolysis be directly observed. Therefore, any attempt to evaluate the virtues or dangers of old repairs can be made only from direct observation. Again, a stereomicroscope is needed to undertake this examination. This effort will be coordinated with Jackson et. al [17].

5) Examination of waterstains. Previous work has identified larger amounts of iron in the tide line regions of the waterstains as compared with values obtained from the Shroud background [6,18]. In paper conservation, iron has been implicated with serious discoloration and brittleness, probably caused from an enhanced role in oxidation catalysis of cellulose [19]. All transition metals can and will promote this degradation pathway in paper [20]. The chemistry of the linen fabric of the Shroud should not be significantly different than the chemistry of linen paper. With this in mind it seems reasonable to examine the waterstains in order to determine if this locally enriched iron region has suffered more fiber damage than cleaner background linen as has been previously reported for image versus non-image areas [18]. Measurements of iron concentration will be determined by Schwalbe et. al in another work package [21].

6) Determination of insect and/or microbiological damage. Very often insect damages may appear similar to other forms of mechanical damage. Also, some microbiological activity resembles iron staining and water damage. Since microorganisms present another deteriorating factor, these should be taken into account during the examination. In this regard, we shall coordinate with the programs proposed by Cairney [22,23] and Riggi [24].

B. Air Pollution Assessment

It is generally acknowledged that the present conditions of storage afford minimal protection against the adverse effects of Turin's urban environment. In buildings without a chemically protected air conditioned system, pollutants such as ozone can attain 60-70% of their outdoor concentrations [20,25,26], with high levels of sulfur dioxide and oxides of nitrogen also reported [27,28]. This can be a general characteristic of buildings where historically important artifacts are housed [20]. In addition, ozone has been found to fade some organic artists' pigments [29]. It is a sufficiently strong oxidant to be used in the paper industry as a raw fiber bleach [30]. Another common pollutant, nitrogen dioxide, is a specific oxidant for the primary hydroxyl on the cellulose chain. This results in increased carboxylic acid groups and a lower overall pH.

With the effects of air pollution on other cultural properties clearly known [31,32], the pollution levels within the Shroud's current storage facility should be monitored. For a comprehensive assessment of the problem, we recommend that a year-long study of air pollution levels be undertaken so that seasonal variations can be included. Since the assessment program will need to continue long after our team has left Turin, we request the collaboration of the Turin authorities in supplying the necessary monitoring equipment.

C. Recommendations for Display and Storage

During exhibition, the Shroud will encounter many destructive influences such as light, humidity and other stresses.

Light levels can easily be specified for the exhibition of photochemically sensitive materials [33-36]. Generally 50 lux is suggested with the ultraviolet light component totally removed by filtration. Higher light levels only encourage chemical attack by atmospheric oxygen, accelerated in the presence of moisture. We propose to measure cathedral light levels under exhibition conditions. We also will use the photolytic and thermal aging data collected by Jackson et. al. [37].

The ideal relative humidity for cellulosic materials has often been suggested at around 40% to retard chemical pathways [38]. However, it has often been felt that these values were too low to adequately provide composite materials of sufficient fiber-fiber plasticity [38]. Thus, for objects composed of a few dissimilar components, higher relative humidities (up to 60-65%) are appropriate. Still higher relative humidity is not recommended due to the problems inherent in mold growth above 70%. Care should be taken in an exhibition case design to anticipate problems of hygroscopic movement within the object. It has been shown jointly from work done at the Los Angeles County Museum of Art and Jet Propulsion Laboratory, that these changes can occur even in well sealed encapsulated environments [39-41]. A factor that also influences relative humidity is uncontrolled, rapid changes in temperature. In another work package, temperature changes of the Shroud during the initial unrolling will be measured thermographically [42]. In addition, a recording thermohygrometer examination will be included in the air pollution assessment program.

Mechanical stress and textile response, termed strain, has been briefly discussed under Examination of Physical Characteristics section. The Shroud remains a three-dimensional object and any mounting which unduely presses against the textile must respect the integrity of this structure.

The Shroud's storage follows an old and rigidly prescribed method. Some aspects of this method may not be consistent with modern concepts of fragile textile care. We think that a review is needed if for no other reason, than to raise the consciousness of the Shroud's caretakers.

III. METHODS AND MATERIALS

Investigations will rely heavily on on-site inspection with standard manual equipment including magnifying glasses and stereomicroscopes (with camera). Video and audio documentation coverage as provided under a separate work package [43] is essential. The pH and air pollution measurements and data collection are straightforward and will be performed on site. The tensile strength and artificial aging experiments will, of necessity, be performed at our home laboratory. Conservation data obtained by other investigators from other work packages [17,21,22,23,24,37,42,43, 44-54], will be incorporated into a complete conservation review of the Shroud of Turin with recommendations.

IV. EQUIPMENT REQUIRED

A. Turin

Two pH meters will be provided by the team including a surface contact electrode, bottled nitrogen and other support housings for acidimetric measurements. A steromicroscope is required from the STURP team's equipment pool which should include a color vidicon camera and video tape recorder. Also sound recording will be of great help during the examination.

Equipment required for the Italian co-sponsored environmental assessment program includes two Dasibi Model 1008-PC ozone monitors along with two precalibrated nitrogen dioxide monitors. All four instruments should be linked with their own individual strip recorders. (A Bausch & Lomb, "Omniscribe" works well, however, it should be a model which is designed for very slow speed - typically, 0.042 cm/min.) Two recording thermohygrometers will also be required in Turin.

B. Home

In order to provide better informed recommendations on ultimate storage conditions, old and new linen will be subjected to studies with accelerated aging in different inert atmospheres in different relative humidities. These experiments will be calibrated with the laser on site aging studies [37]. The use of differential thermal analysis (DTA) may be employed to evaluate the best inert gas for long term storage under low temperatures. Nitrogen has been compared with air [55] but no study has been made with aged linen and other inert gases or gas combinations. Some of these studies will be carried out at North Carolina State School of Textiles at Raleigh by Professor of Textiles, Dr. S. Hersh.

V. TIME REQUIRED

1.	Pre-Shroud in Turin	2 hours
2.	On Shroud	12 hours (in two blocks of six)
3.	Post-Shroud in Turin	2 hours
4.	At home	5000 hours (includes time for artificial aging experiments)

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CONSERVATION TESTING ON THE SHROUD OF TURIN - B

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I. OBJECTIVE

We propose to conduct a series of three experiments all pertaining to the problem of preserving the image contrast. The first experiment is designed to measure the rate at which the cloth is deteriorating. The second examines the types of pollutants in the storage environment of the Shroud. The third is designed to measure the effects of low-Z elements, primarily calcium and magnesium, on the degree of local discoloration due to fabric deterioration.

II. STATEMENT OF THE PROBLEM

The most immediate of current problems facing Shroud researchers is in the care and preservation of the cloth and its image. Until now, there appears to have been little, if any, concerted effort in the area of conservation. To our knowledge, only Curto [1] and Pellicori [2] have published any specific recommendations.

In this work package, we intend to make conservation our primary goal. Our work will be coordinated with a supporting team of textile conservators. Although final recommendations for display, handling, and storage are primarily their responsibility, these decisions must ultimately rest on detailed knowledge of the physical conditions of the Shroud and its environment. Our intent is to provide data for this evaluation. Of the many specific concerns in the area of conservation, we limit our attention first to the problem of preserving the image contrast. The following experiments address questions concerning rates of degradation of the material and factors that affect these rates, the types and extent of environmental pollution and the elemental composition of the fabric.

A. Degradation Rate Study

Perhaps the most important finding of the research following 1978 is the determination of the body image composition. We believe the translucent yellow discoloration resulted from an oxidation-dehydration reaction [3]. Chemically the image is similar to the product of natural aging in cellulose. The body image apparently stands in visual contrast to the base material because the extent of the molecular degradation is greater in the image area. It is probable that visual contrast is decreasing. The decline

is probably due not so much to the direct effects of aging on the image portions of the cloth as they are to progressive yellowing of the nonimage or background areas.

It is unlikely that discoloration effects are measurable over a six year period, precluding comparison of current reflectives with those measured in 1978. At the midvisible wavelength of 550 nm, Gilbert and Gilbert [4] measured the absolute reflectivity of the Shroud background to be 35%. Pellicori [5] measured the reflectivity of new linen at the same wavelength to be 58%. If we assume this discoloration occurred over a minimum 1000 year period due to natural aging alone, we estimate an average reflectivity change rate of 34%-58%/1000 years =-.024%/year (Note that the natural discoloration rate would be less if part of this discoloration was due to the 1532 fire or if 2000 years are assumed). Over a six year period, this amounts to a change of -.14%. Given that the reproducibility scans of Gilbert's data were accurate to within about 4% [4], it would appear that reflectivity changes over a six year time span are within instrumental uncertainty. We therefore propose to perform artificial aging calibrations in which degradation with time at various temperatures lead to a discoloration of the base material. The extent of this damage will be measured by optical reflectance spectrometery. We propose to remove a small fabric sample (ca 1 cm^2) from the Shroud. This material along with similar fabric samples of different physical and chemical makeup will be subjected to a series of standard artificial-aging experiments.

Generally, these tests will have each sample held at some moderately high temperature (ca. 120°C) for periods of hours. After the baking period, the optical reflectance characteristics of the samples will be observed and recorded. This program, repeated a number of times, should give a rate of discoloration for each sample corresponding to the baking temperature. Results on the Shroud sample will be scaled to present storage temperatures, as measured in another work package [6], to provide an estimate for the ongoing rate of deterioration. The combined data should provide further information about the types and rates of damage that are likely to occur as a function of the physical and chemical makeup of the cellulose. These experiments will be coordinated with the on-site accelerated aging experiment proposed by Jackson, et. al [7] which will serve as an independent confirmation of the degradation rate measurements. However, if Jackson's experiment is successful, this experiment will not be performed and, accordingly, no sample will be required.

B. Air Pollution Assessment

It is generally acknowledged that present conditions of Shroud storage afford minimal protection against the adverse effects of Turin's increasing urban/industrial environment. The effects of air pollutants such as NO_2 and O_3 can accelerate the degradation and discoloration of the cloth. This deterioration cannot be prevented altogether, but steps can be taken to retard the process.

We think an essential task in the evaluation program is to measure the types of environmental pollution present and their relative concentrations. As one phase of this study we propose to review any pertinent data that already exists and take simultaneous indoor/outdoor measurements of major known pollution species. To do the latter will require temporary access to

at least two sets of portable pollution monitors. We desire and encourage the collaboration of Turin authorities in performing these measurements and suggest that arrangements be made to use local equipment. A joint effort is highly desirable because the results of such studies are often sensitively dependent on climate and season conditions. There is a need for regular monitoring over extended periods, and only local people can perform this ongoing work.

It would also be essential to collect long term data from within the cathedral itself. But, if internal monitoring is impractical, an alternative is to measure the pollution outside the building. These data will then be applied in mathematical models [8] to predict inside levels. Although long term monitoring must be arranged with the local authorities, there are additional measurements required if the modeling approach is adopted. Estimates of the air infiltration rates, the building materials, the building volume and surface area, are necessary input data. While in Turin, we shall evaluate these parameters.

C. Further Analytical Studies

Schwalbe, Jenkins, and Riggi [9] and Carter, Jumper, and Carriveau [10] in separate work packages are proposing to conduct an extensive series of x-ray fluorescence (XRF) measurements on the Shroud. Among the experiments described is a determination of the light-element composition of the cloth. Magnesium, calcium, and iron are of primary interest. From a conservation standpoint their relative concentrations are quite important. Chelated calcium and magnesium inhibit certain kinds of degradation; generally, their presence benefits the preservation of the cellulosic materials. Iron, on the other hand, promotes discoloration.

To supplement the x-ray fluorescence work, we now propose to measure the surface pH and the UV-visible transmission at the same locations where the elemental analyses are obtained. If calcium and magnesium do function as buffering agents, we expect large concentrations of these elements to correlate with low pH measurements. Also, if the optical data [11-14] provide a measure of cloth degradation, we should find positive correlations between pH and the degree of local discoloration.

The goal of this phase of our study is to understand better the relationship between the elemental composition of the cloth and its state of preservation. It is important to confirm the predicted effects of the light elements on the visual appearance of the fabric. Also, with the nondestructive technique of x-ray fluorescence, we may eventually be able to identify locations on the Shroud that are particularly susceptible to continuing damage.

IV. EQUIPMENT

The first phase of the work, described in section A, will require no measuring apparatus. If permission is granted for the artificial aging experiments (Removal of cloth and/or laser aging [7]), we shall comply with any instructions of the Cardinal, or his designated representative, in performing these studies.

For the air pollution assessment, we will require the active collaboration of the local Turin authorities both in securing the required monitoring equipment and in collecting long-term data. The types of tests

we recommend are described in Technical Manual of the American Association of Textile Chemists and Colorists (1969). For example, passive techniques for measuring the effects of ozone are respectively the AATCC Test 109-1963/1971 and the AATCC Test 129-1968 for conditions of moderate and high humidity. The success of this phase of the work, as we said, depends critically on the interest and accessibility of our Italian collaborators.

Finally, for the analytical studies that will coordinate with x-ray fluorescence, we require a minimum of extra equipment. The optical data collection are described in other work packages [11-14]. The pH measurements will be performed with standard techniques. However, because these involve some wetting of the cloth surface, some prior control experiments will first be run to assure that no damage will result from the process and that no crease information is destroyed for the foldmark examination [15]. If visible damage is unavoidable, this portion of the experiment will be aborted, and only the nondestructive optical and x-ray measurements will be conducted.

VI. TIME REQUIRED

The following "on Shroud" estimate is the time necessary for removing the fabric sample described in section "A". In principle, a longer period will be required for the pH and optical measurements described in section "C". However, the time for x-ray fluorescence has already been allocated in separate proposals [9,10]. The supplementary measurements described here will be carried out simultaneously and require no additional time.

A.	Pre-Shroud in Turin:	2 hours
B.	On-Shroud in Turin:	4 hours
C.	Post-Shroud in Turin:	6 hours
D.	At home:	100 hours

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DATING THE SHROUD OF TURIN USING RADIOCARBON ANALYSIS

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I. OBJECTIVE

To obtain an accurate calendar date, D, of the Shroud with limits of probable error, σ, (D $\pm \sigma$ yr) from radiocarbon analysis of very small samples from the Shroud of Turin.

II. STATEMENT OF THE PROBLEM

Neutrons produced by cosmic rays in the earth's atmosphere interact with nitrogen atoms (N) to form a heavy isotope ($^{14}_{6}C$ or C-14) of ordinary carbon ($^{12}_{6}C$ or C-12) according to the nuclear reaction

$$^{14}_{7}N + ^{1}_{0}n \rightarrow ^{14}_{6}C + ^{1}_{1}H \qquad (1)$$

The ratio of C-14 to C-12 is quite small - about 10^{-12} - and the two kinds of carbon are practically indistinguishable from each other chemically and biologically. Carbon atoms are oxidized to carbon dioxide (CO_2) in the atmosphere and this enters into the life cycle of living organisms. Plants and animals thus have a C-14/C-12 ratio of 10^{-12} at "death" - i.e. the time when the organism leaves equilibrium with the atmosphere. C-14 is radioactive, however, and decays back to nitrogen according to the equation

$$^{14}_{6}C \rightarrow ^{14}_{7}N + ^{0}_{-1}e \qquad (2)$$

C-12 is radioactively stable. Thus, the amount of $^{14}_{6}C$ changes with time after "death" but that of $^{12}_{6}C$ does not.

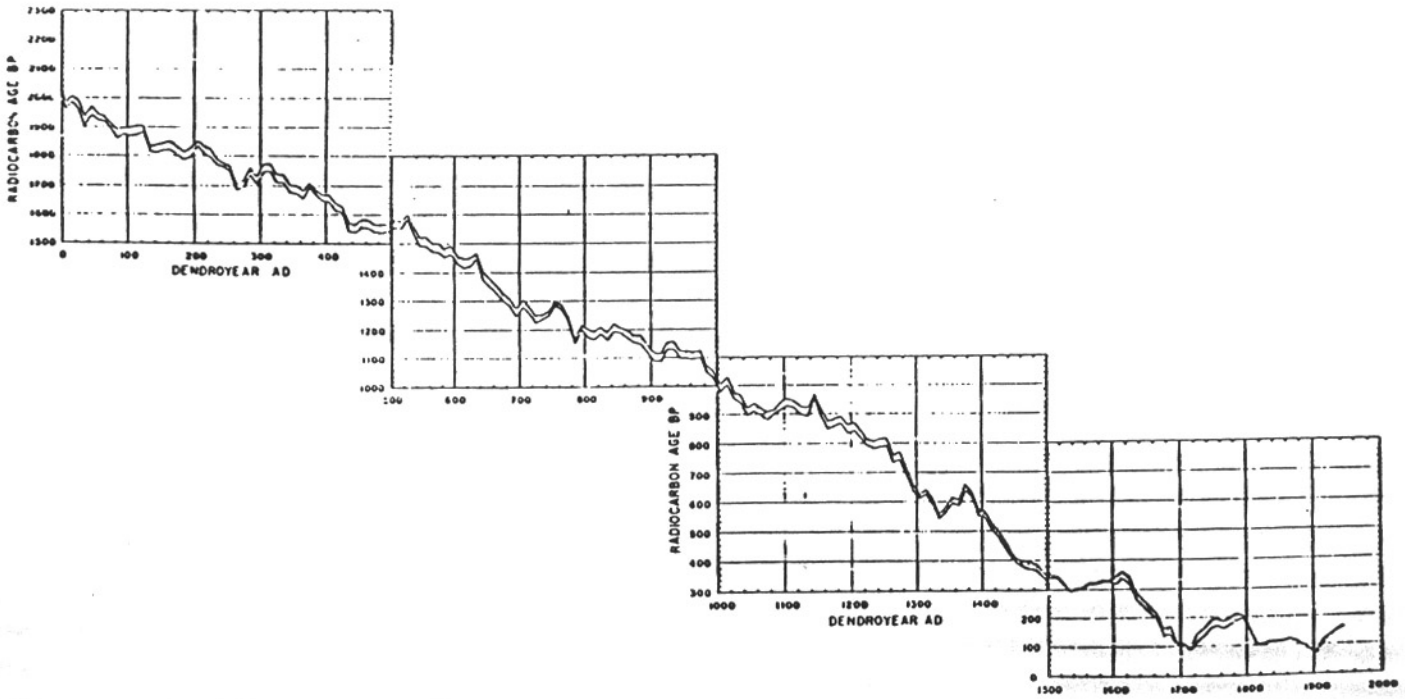
Almost 40 years ago W. F. Libby showed that the "age" of an object containing carbon could be determined by measuring the relative amounts of C-14 and C-12 it contained [1]. In the Libby method, this "age" - a radiocarbon age - is found by (1) measuring the radioactivity of the object (or sample), (2) assuming a constant value of the radioactivity of the sample at the time of "death", and (3) using the known C-14 decay rate law of

$$C(t) = C_0 \exp(-kt) \qquad (3)$$

where: C_0 = radioactivity (counts/unit time) of carbon sample at time of "death", i.e. time = 0
$C(t)$ = radioactivity of carbon sample at a later time, i.e. time = t
k = the decay constant of C-14.

Unfortunately, the value of C_0 is not truly invariant - it changes from year to year and century to century due to a number of factors. After much research and study, the magnitude of this variation has been determined. Corrections for the smooth long-term variation and superimposed short-term fluctuations have been calculated [2,3]. Figure 1 (the Stuiver correction curve, vid, ref. 5) is the time transformation generally accepted for the last 2000 years. This is the curve that will be used in obtaining a chronological date from radiocarbon data obtained on samples of the Shroud of Turin. Accuracies, σ, of ±120 yr for "time-of-Christ" era and ±250 yr for the AD 1300s can be easily obtained. Ages for objects older than this can also be determined, probably up to several tens of thousands of years. These dates agree quite well with those determined by other methods [4].

For many years there was only one method for determining the C-14 concentration - counting the electrons given off in C-14 decay (eqn. 2) over a long period of time (months). Until about 1975 this method required 1 to 10g of carbon, usually about 3-30g of the object. This relatively large



Stuiver calibration curve[2]
for conventional radiocarbon dates
(from ref.5)

sample size prevented a great number of objects from being "dated" [5]. Since that time, however, counting methods have been improved so much that now only milligram (1 mg = 10^{-3} g) quantities are needed [5]. However, measurement times are still about the same, i.e., several months. The accuracy of this method has been established many times, usually by checking the dates it gives against those obtained from tree-ring counting techniques.

Recent use of the counting technique by two of the listed analytical investigators - in experiments similar to the one we propose on the Shroud - is described in reports by Harbottle, Otlet, et al [5,6]. The chronological ages of (1) a cloth purported to be the Robe of the Blessed Virgin, (2) a piece of wood said to be from the True Cross, and (3) a smelted iron object (the Frobisher Bloom) containing an extremely small amount of charcoal have been determined. The ± values on the dates obtained averaged 130 years. Both laboratories (Brookhaven and Harwell) now radiocarbon-date routinely and are acknowledged leaders in the field.

Within the last decade a new technique in carbon-dating has been developed [7,8]. This is known as the accelerator method. Instead of recording radioactivity and determining C-14/C-12 ratios, ions (charged particles) are produced from all types of carbon present in the sample, counted by mass spectrometer means, and the C-14/C-12 calculated. From calculations involving the same physical-chemical laws as discussed with the counting technique, a radiocarbon age is obtained. Using the same correction factors discussed above, this age becomes the desired chronological age. This method is the one developed and used by Gove, Damon, Hall, and Oeschger of this work package.

Much can be said for each method. We are indeed fortunate that the best laboratories in the world, employing both techniques, have agreed to work together and obtain one date for the age of the Shroud. The laboratories listed as investigators and consultants have already carried out a cross-calibration of individual equipment and procedures using samples supplied by Dr. M. S. Tite of the British Museum. One was Egyptian linen from the third millenia BC; others were from the 7th to 15th centuries AD. A second calibration - using samples of oxalic acid ($H_2C_2O_4$) prepared from modern and fossil carbon - also has begun. Dr. George Coleman is coordinating this work. These data represent the most extensive calibration in the history of radiocarbon dating.

Even with good experimental data and time transformation, an erroneous date for the Shroud age is sometimes posed as possible due to cloth contamination (1) picked up in its long history of movement from place to place, (2) from atmospheric pollution (e.g., the fire at Chambery in AD 1532), and (3) from human handling. We think this is now unlikely for two reasons: first, the current preparation treatment of samples is known to quantitatively remove both organic and inorganic accretions; and second, calculations using eqn. 3 show no significant contribution to the calendar date with less than five percent (5%) contamination. Normal radiation-based phenomena such as ${}^{18}_{8}O + \gamma \rightarrow {}^{14}_{6}C + {}^{4}_{2}He$ or ${}^{13}_{6}C + {}^{1}_{0}n \rightarrow {}^{14}_{6}C$ also are sometimes

:ited as possible contributors to an age error, especially since the age-

letermining ratio of C-14/C-12 is only about 10^{-12}. These reactions do

xist, but are unlikely to contribute to the $^{14}_{6}C$ concentration because either the gamma-ray nor neutron flux can be expected to have been anywhere lear high enough in the areas where the Shroud has been kept over the :enturies. Further, contamination either by external particulates or :adioactivity are likely to be spatially nonuniform over the entire Shroud)wing to the large size of the Shroud. Thus, if such contaminations are ;ignificant, C-14 dating of samples taken from different locations of the ;hroud should reveal such perturbations.

III. METHODS AND MATERIALS

We request permission to take samples from several different non-image locations on the Shroud. Two hundred milligrams (200mg) from each of the)urned areas under and around the patches (excluding the dorsal shoulder foldmark intersection area [9]) will be trimmed away. This material can be removed without affecting the visual appearance of the relic or causing damage to the fabric structure. Conservatively, this quantity will provide three samples for each participating laboratory. We also request 200-mg-samples from the presumed side strip, one patch, and the lower right-hand corner of the Shroud. Each such sample is the equivalent of about two square inches (10 cm^2) of material. We also request a 200-mg-sample from the Holland backing cloth. This latter forms an internal standard of known date to go with our unknown. An external standard will come from two samples from other sources, both of known origin and date.

All samples from the Shroud will be removed by Dr. McNeil [10] under the supervision and with the help of Drs. Dinegar, Harbottle, and Gonella of Turin. The latest in cutting and precision excising tools of the hand type will be used.

All samples will be delivered to the laboratories at the same time, identified by code number/letter. The key will be made up by and known only to Drs. Dinegar, Jackson, and Jumper of STURP, and Gonella of Turin, none of whom will be involved in the actual experimental laboratory work. Since neither of the two methods of radiocarbon dating exhausts the samples, an exchange between laboratories for repeat measurements can and will be made. Thus, an excellent set of data statistics will be obtained.

Upon completion of dating experiments, each laboratory will send the results to Dinegar, Gonella, Jackson and Jumper for collation. The date and place of the public announcement will be recommended by STURP to the Cardinal Archbishop of Turin after agreement by the participating laboratories.

IV. EQUIPMENT

Sample excising tools [10].

V. TIME REQUIRED

A.	Pre-Shroud in Turin:	4 hours
B.	On-Shroud in Turin:	6 hours
C.	Post-Shroud in Turin:	2 hours
D.	At home:	9 months

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DISCUSSION SESSIONS AND MICROSCOPIC EXAMINATIONS

PRINCIPAL INVESTIGATOR: E. J. Jumper, Ph.D.
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I. OBJECTIVE

To conduct organized discussion sessions in Turin to compliment the testing being conducted concurrently.

II. STATEMENT OF THE PROBLEM

At the time of the 1978 testing of the Shroud of Turin, a great deal of observational data was collected that was not part of that sought by the specific tests. These observations were later found to be of great importance in the interpretation of the specific findings of the formal tests. Examples of this sort of data can be found in several of the published papers [1, 2, and 3]. They include comments on the depth of the body image, cementing together of fibrils, etc. For the most part, these data were recorded by various researchers in their test journals; however, much of these types of data were recorded later as recollection. In some cases, investigators began to doubt the correctness of their on-site observations recorded in their journals. In these cases it was helpful to compare recollections, and in some cases such exercises brought to mind on-site discussions from the time of the 1978 testing which led to a consensus of opinion regarding specific observations. It is clear that such discussions lent credibility to the specific observations. Since the 1978 testing, certain other observations have been made from the various photographs, etc., which may have important implications, such as the halo effect around blood flows suggesting the order in which the images may have been formed on the Shroud [1]. These after-the-fact observations must be explored closely on the Shroud itself in any new testing and in a way which will lead to as much consensus of opinion as possible. Further, on-site discussions can be an invaluable catalyst in redirecting examination methodology for optimal data return, if indicated.

Thus, it is proposed that discussion sessions be set up at regular intervals throughout the duration of the testing. It is desired that these sessions be attended not only by STURP but non-STURP personnel as well so as to optimize information exchange and new ideas. The sessions will be chaired by a discussion monitor. The monitor need not be the same person for every session and, in fact, might be best chosen in accordance with the topic of discussion, if such topic is clearly identifiable before the session. Each session will start with a listing of the most important findings since the last session followed by directed discussion to explore their implications. These sessions will also include microscopic observations of the Shroud.

III. METHODS AND MATERIALS

The format of the discussion sessions need be detailed no further; however, the arrangement of microscopes and other materials is of interest. To this end, three stereo microscopes (10X - 50X) mounted on vertical stands will be required on site. Two of these microscopes will be equipped with camera tubes with Nikon T-mounts so that photographic transparencies can be made to help document the points being made during the discussions. The third microscope will be equipped with a small portable color video pack. At each of the three microscope stations, instruments such as dissecting needles will be available on the stand as well as a number of jeweler's loops for inspection of sites requiring less magnification. Journals will be kept by each of the session participants along with an official journal for each of the sessions. Audio tapes of the overall session will be made for transcription at a later time. Additionally, each microscope stand will be equipped with a small cassette audio recorder for the recording of film frames, observations, etc. Video recordings of the overall events for each session will also be made for use in later interpretations of the observations. Prior to the testing, detailed lists of important items for observation and discussion will be compiled from questionnaires to be circulated by mail to as many people as possible who have an interest in the Shroud. This list will then form a basis for topics of discussion to be addressed at the scheduled sessions; however, as noted above, topics that come up from ongoing testing will carry at least equal weight for session topics. The microscopes, while they will be available for other uses during non-session times, are not proposed to supersede other microscopical studies proposed by other researchers.

IV. EQUIPMENT

The equipment required for this proposal includes three complete stereo microscope and associate equipment setups. Additionally, three carrying cases suitable for shipment as luggage must be designed and constructed so that no shipping expenses need be incurred. The systems will include the Unitron Model ZST Zoom Stereo Trinocular Microscope and associate equipment. The audio requirements include four tape recorder units, three of the micro-recorder type, the fourth a larger system to record the overall session. We intend to take advantage of the presence of video equipment and operator proposed by other researchers [4].

V. TIME REQUIRED

IN TURIN:

ON-SITE TIME: One hour should be allowed per session. The exact number of such sessions is open to discussion: however, one every twelve to twenty-four hours seems to be the optimum that should take place. (14 hours)

OFF-SITE TIME: Approximately 12 hours of set up time prior to the testing will be required. Additionally, approximately one hour of preparation time will be required per session and one hour of time after the completion of each session.

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ELECTRONIC ON SITE DATA CAPTURE FOR IMAGE PROCESSING OF THE TURIN SHROUD

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COINVESTIGATORS: V. D. Miller
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C. C. Avis
Jet Propulation Laboratory

I. OBJECTIVE

A. To acquire electronic imagery for later distribution to qualified international investigators for image analysis.

B. To provide on-site, real-time data acquisition and image analysis for other on-site investigators.

C. To provide additional video coverage and documentation for technical, analytical purposes concerning several other investigations being performed.

D. To provide first generation image data for conservation and image formation mechanism studies. (Depending upon the availability of special filter materials currently under development, to perform energy subtraction radiography (ESR), which is a form of remote sensing used to create image gray values from materials based on differences in atomic number.)

II. STATEMENT OF THE PROBLEM

A. Introduction

In general terms, the image on the Turin Shroud contains two types of scientific information which involves the study of the chemical composition of the image without regards to image or pattern structure. The second deals with the image structure without regards to chemical composition.

Both types of information are fundamentally different but complimentary. A serious study of the Shroud image should therefore ensure that both forms of information are retrieved, properly studied, and integrated into a correct scientific picture as to the nature and cause of the image.

In this proposal, we offer to extract image analyzable information from the Shroud directly by on-site electronic means. That is, we propose to obtain a complete numerical representation of the image by firsthand electronic data capture rather than scanning intermediate photographic imagery. This is not meant to supplant but to compliment photographic data. Photographic imagery is still the best way to obtain qualitative representations, while direct electronic data capture is probably the best method to obtain reliable quantitative information. In short, photographic data is an indispensible guide for any serious quantitative studies.

There remain numerous image studies which can still be performed. There are, of course, studies which could either confirm or augment previous image analyses dealing with, for example, resolution, image enhancement, and three-dimensional interpretation [1]. But there are new studies which can only be performed with additional data. Some of these are: determination of image penetration by a numerical comparison of calibrated transmission and reflectance data (as in another proposal [2]), comparison of the relative reflectances of the general frontal and dorsal images (important for distinguishing between proposed image formation mechanisms) [1], examination of dorsal image for possible three-dimensional encodement [1], close-up examination of eye regions for subsequent studies of coin inscription hypothesis, objective determination of yellow to white fibrils in the body image areas, possible image reconstruction in burn areas as proposed by Schwalbe [3], determination of the limits of body image (important for evaluating possible cloth-drape distortion effects [4]), examination for subtle discoloration variations associated with fires, aging, or historical display configurations [5], mapping of foldmark distortions by scanning the off-normally illuminated Shroud [5], etc. In addition, there exist conservation reasons for acquiring these data because, unlike photographic products, electronic numerical data do not degrade and therefore the present, quantitative condition of the Shroud image can be preserved indefinitely.

B. Principal Purpose

The principal purpose of the proposed experiment is to acquire electronic imagery for later distribution to qualified international users for image analysis. The cameras to be used will be capable of sensing electromagnetic energy from approximately 1100 nanometers (reflected infrared) through visible light in monochrome at selected, filtered wavelengths and in natural color composed of visible light. The color signal will be structured to allow analysis of the hue (wavelength of dominance), intensity, and saturation (white component).

C. Secondary Purpose

The secondary purpose of the experiment is to provide on-site, real-time image analysis. This is intended to be available to all imaging experiments and will be conducted for the purpose of quality control, lens filter, lighting and other parameter evaluations, and to perform "quick

look" analyses of data collected on site. This immediately available data can be used at the proposed discussion session [6]. The equipment to be used for this purpose features edge enhancement, density slicing, addition, subtraction, multiplication, division, "logic" ratioing, contrast, polarity control and enhancements, texture enhancement, pseudo-three-dimension (density/ isometric) projection, density profiling, image geometry control, spatial editing and marking, and spatial measurements function. Although all of this capability is provided in the instrument, the equipment is still quite portable and simple to operate.

D. Advantages of using electronic imagery

1. You see what you are collecting as data as you are collecting it (in other words, a numerical representation, both spatially and spectrally by density, is made immediately on-site;

a. Infrared and other parts of the spectrum are viewed as monochrome images over the filter bandwidth in real time.

b. Focus, "exposure-density" curves, and dynamic content are viewed in real time.

2. Data collected through electronic means are often better suited for analysis by electronic means;

a. Less "process loss" and better control of image quantifiable parameters can be maintained (e.g., specific densities over several images)

b. Methods which effectively extend the useful dynamic range of image data during data capture can be implemented.

3. Large amounts of data can be stored on electromagnetic media (video tape) at low cost, with very few cassettes that can be easily and rapidly reproduced for distribution or reformatted to digital data sets at a later date.

a. Video tape can be viewed through inexpensive and readily available consumer products (3/4 or 1/2 inch VHS format)

b. Video conversion from the RS-170 (U.S. standard format to other common formats (i.e., PAL) can be easily and inexpensively accomplished.

c. An audio track on the tape will be used to "log" the process of data acquisition to further enhance documentation and to make data searches faster and easier to accomplish.

d. Video captures a frame of imagery every 1/30th of a second; thus, it is a continuous means of rapidly capturing serial strips of information without concern of data loss due to improper overlap of frames common to film processes.

4. Video is instantaneous and requires no chemical processing or dark room activities. Yet, it can be used with film products.

5. Data collected by these processes can be universally standarized as to precision, spatial resolution, and other image acquisition qualities (all specifications and limitations can be documented and that documentation can be supplied with any replicated materials). In other words, all image analysis investigators will be able to start with the same, standardized set of first generation image data. This will allow various computer image processing experiments to be easily intercompared and reproduced without having to be concerned about variations in scanning or photographic parameters.

E. Disadvantages of using electronic imagery

It is important to note that video has several disadvantages, too. Spatial resolution per frame of imagery (resolution per format size is low compared to film; hence, close up scans must be used to compensate. Certain dark room processes using lighting (dodging), push-processes, and other techniques (masking, dual-negative enhancement printing, etc.) are difficult, if not impossible, at the current state-of-the-art to accomplish with electronic imagery. Therefore, it must be understood that it is not the intention of this equipment to replace film or other types of imagery, but rather to compliment and supplement, as well as to perform those tasks which can only be done by, or can best be done, by electronic imaging techniques. It is intended to be an asset available to the entire team and other qualified international users for tests and measurements when and where it is both applicable and desirable to use it.

F. After on-site work is completed, data can be made available, at cost, on several different media and in several different formats.

1. Digital data will be available on "floppy disks" and magnetic tape.
2. Analog type video data will be available for reproduction in both U.S (RS-170) and European (PAL) formats on half inch and three quarter inch video tape, VHS, Beta I, Beta II, U-Matic, at condensed or standard playing speeds.
3. These data can be made available in these and other forms to qualified international investigators for their own computer-based image analyses.

III. METHODS AND MATERIALS

A microcomputer (8086/8087) is incorporated in the instrument to be used for quick look and some of the subsequent image analyses. A key board/front panel is used to control the operations. Some functions are totally digital in nature while others are either all analog or partially analog/partially digital. All functions, with the exception of contrast and brightness enhancements are under digital control and that control is given to the operator through simple-to-use prompts and function keys.

The complete system includes two light tables, copy stands and monochrome cameras with spectral filters, close-up attachments and zoom lenses. A microscope and camera adapter is also included. These devices will permit the analysis of hard-copy photographic and graphic data acquired on site, as well as the analysis of small portions of the Shroud with the microscope attachment.

Principal data acquisition (see Principal Purpose, Section II-B above) will be accomplished first with an electronic data scan of the entire Shroud in one view in reflected light. This will be preceded and followed by a scan with a reflectance screen in place for subsequent illumination normalization by computer processing. After this sequence, the Shroud will be illuminated with raking-light (grazing angle illumination) and an electronic image recorded of the entire Shroud. This data will be used in another work package [5]. Reference scans of the reflected screen before and after this recordation will again be made for later illumination normalization. Since creases and foldmark structures are to be recorded, closeup imagery will be accomplished with appropriate reference images as deemed necessary (see below). This will be followed by an electronic scan of the entire Shroud in one view, but with the Shroud illuminated by transmitted light. Like the reflectance imagery above, this will be preceded and followed by an electronic scan of a translucent screen for illumination normalization by subsequent computer processing. Closeup scans of the transmitted light imagery will be accomplished as necessary (see below). This data will be used or compared with that of another work package [2]. Finally, the general sequence will be concluded with an electronic scan of the backing cloth along with appropriate calibration reflectance, off-normal illumination, and transmission scans as discussed above. In all cases, corresponding photographic coverage will be made for qualitative comparisons with the quantitative electronic data.

Following these general sequences, closeup imagery will be acquired with a physical resolution of 100 pixels to the linear inch (10,000 pixels per square inch) over the entire Shroud, in two passes with a monochrome camera and selected spectral filters, and one pass with the color video camera. This will be accomplished under reflected, transmitted, and off-normal illumination, as well as off the backing cloth under these varying lighting conditions. It is our intention to use the proposed equipment with the existing STURP photographic camera rail frame, previously employed in 1978, to properly position a film camera and illumination sources relative to the Shroud in order to image the entire Shroud electronically with various scales, spectral filters, lighting enhancement response curves, and other measures as may be deemed valuable while on-site. All data will be collected on video tape with audio comments referenced to the 1978 coordinate system. Appropriate reflectance and transmission calibration screens will be used and appropriate photographs taken. Data will later be reconstructed into a single digital data base composed in a "frame-mosaic" manner thus enabling digital reconstruction of any portion of the Shroud, or the entire Shroud to any resolution up to 1/100 of an inch, the apparent thread repetition length of the Shroud (Higher resolution will be scanned in special areas using a microscope attachment; see below). The parameters of data capture activities will be defined and sample sites

selected for introduction of gray scale, color, and graticular data for control in analysis.

We shall also collect spectral information using a series of narrow-band (10 nanometer) filters to scan, at a higher scale (lower resolution), the entire Shroud. Extensive studies will be conducted on selected features such as stains, burn areas, patch areas, "boarder cloth", and folds.

Finally, we shall electronically scan the image at high magnification in selected areas through a microscope at roughly 50-100X. Thus, we will obtain image data pertaining to yellow/white fiber ratios and blood closeup imagery.

Further details of the equipment and previous image analysis studies relating to the Shroud can be found in references 7-18.

IV. EQUIPMENT

A. In Turin

(Quantity-Description)

1-Measuronics System II electronic image processor.
2-Hitachi, MOS, solid-state broad-spectrum video, electronic camera.
2-Primary color spectral filter sets.
1-Microscope lens and attachment sets.
1-Hitachi, MOS, solid-state color electronic video camera.
1-Vidicon, three-tube, color camera.
1-Shading corrected vidicon monochrome, broad-spectrum camera.
2-Back lighting sets.
3-Top lighting sets.
1-Set of 10 nanometer spectral bandpass filters for broad spectrum coverage.
3-Video tape recorders and supply of tape.
2-14 inch, high resolution NTSC/RGB, color video monitors.
2-Lapel/necklace microphones.
2-Copystand assemblies for cameras.
1-CRT terminal for keyboard and floppy disk drives with supply of disks.
1-Set of ESR filters (if available).
1-Camera positioning rail frame (as used by other investigators in previous 1978 studies).
1-Video distribution amplifier
1-Set of cables, power strips, and cords.
1-Set of miscellaneous tools.
1-Oscilloscope
1-Reflectance illumination calibration screen.
1-Translucent transmission illumination screen.
1-1978 Shroud table.

B. At home-Various image processing computers and data duplicators as determined by users.

V. TIME REQUIRED

A. Pre-Shroud in Turin: 16 hours

B. On-Shroud in Turin: 20 hours (in four blocks of five hours)
C. Post-Shroud in Turin: 4 hours
D. At home: 1-2 years

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FOLDMARK EXAMINATION ON THE TURIN SHROUD

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Kaman Sciences Corporation

COINVESTIGATORS: V. D. Miller
Brooks Institute

J. R. Druzik
Los Angeles County Museum of Art

J. K. Hutchinson
Merrimack Valley Textile Museum

I. Wilson
British Society for the Turin Shroud

Additional investigator - to be determined
(Probably European)

I. OBJECTIVE

A. To thoroughly examine and document the Shroud for foldmarks associated with styles of folding used in its history, in particular those which might be present if the Shroud was once folded as the Mandylion.

B. To examine foldmark intersections with body and blood features for information relating to conservation and image mechanical properties.

II. STATEMENT OF THE PROBLEM

A major problem associated with the Shroud is the uncertainty concerning its history. Radiocarbon dating [1] can tell how much history the Shroud has had, but is unable to establish what that history was.

Inquiry into the history of the Shroud can take two approaches: (1) study of events external to the Shroud which shed light on its history or (2) study of artifacts directly present on the Shroud which record historical information. Such artifacts in (2) are ratios of Carbon-14 to Carbon-12, pollens, wax, fire damage, stitchings, weave structure, particulate contaminations, to name a few.

In this proposal, we consider foldmark artifacts as potential carriers of historical information. These artifacts, unlike random creases, are of importance because they are likely to be associated with manners of display or storage, both of which impact issues related to the Shroud's history.

We therefore propose to examine and document in detail foldmark structures present on the Shroud. In particular, we intend to focus on a particular set of foldmarks discovered during the 1978 testing of the Shroud in Turin. Although these foldmarks are best visible with off-normal illumination, one foldmark can be seen on any good reflectance photograph of the Shroud running widthwise just below the dorsal shoulder area. The location of this foldmark is one-eighth of the way from the Shroud's center

axis, a location consistent with Wilson's hypothesis [2] that the Shroud was once folded in eighths as the Mandylion about 1000 or more years ago. Indeed, other more subtle foldmark deformations have been noted in the 1978 off-normal imagery which seem to be roughly consistent with this interpretation [3]. The conspicuous foldmark at the shoulder region also happens to pass through the 1532 fire patchwork. Mottern's X-Radiograph shows this intersection [3]. The foldmark can be seen propagating underneath the patchwork right up to the edge of the burned Shroud, but there seems to be no detectable disturbance in either the rectangular weave of the patchwork or in the continunity of the foldmark itself. Thus, it seems likely that the foldmark was in place before the 1532 fire which burned away part of the cloth containing the foldmark [3]. Jackson [3] has therefore suggested that this foldmark is a potential candidate for a Mandylion foldline.

These observations need to be evaluated by direct examination of the Shroud. In particular, the folding directions of the presumed foldmark deformations seen in the 1978 photographic imagery need to be established. For these foldmarks to be consistent with Wilson's Mandylion hypothesis, they would have to imply a folding configuration in which the facial part of the Shroud image is centered and on top of the folded Shroud. This is a highly restrictive condition and while not proving Wilson's hypothesis, the theory would be given much support. On the other hand, if no such foldmarks are observed, when it seems reasonable that they should be there [3] (note that if the dorsal foldmark can be shown to predate the 1532 fire, this demonstrates foldmark survivability over century time scales, whether or not this foldmark is a Mandylion foldline), Wilson's hypothesis would be in serious doubt.

We shall also examine the Shroud for other foldmarks and artifacts which might reveal different folding patterns. We expect to see foldmarks from the 1532 style of folding. But others associated with perhaps the triple burn holes, which are clearly not associated with the 1532 fire, might be detected. Thus, we may learn something of the history of the Shroud through a study of foldmarks.

The procedures to be used are straightforward and simple, require little logistical support and time, involve no hazards to personnel or the Shroud, are inexpensive, and involve an international mix of research talent. As discussed above, the probable payoff is high since the Wilson hypothesis can probably be definitively tested.

In addition to study of foldmarks as relating to history, we propose to study the foldmarks from a conservation point of view. Foldmarks intersecting the blood images should provide valuable information concerning the integrity of blood images with respect to underlying mechanical strains due to cloth creasing. If fracturing has occurred in foldmark areas, it could conceivably lead to erosion of the blood encrustations at those sites. It should be noted that the 1978 examination revealed a multitude of random creases covering the entire Shroud surface and which undoubtedly intersect blood materials in many locations. We shall be particularly attentive to conservation issues such as possible blood fractures as they relate to foldmark deformations. It has also been suggested [4] that the many random crease structures visible in the 1978 raking light images may be due to assymetric expansions and contractions of border fabrics to which the Shroud

is attached. In addition, rolling the Shroud has visibly formed undesirable creases on the Shroud [3]. These and other possible generators of random creases will be studied directly on the Shroud with recommendations given for their avoidance and/or removal. We also propose to examine in detail how the random crease structures intersect the body image. In particular, if a paint medium is present, stiffening of the cloth might show up as detectable perturbations [3]. If, however, the image was produced thermally as from a heated statue or bas-relief, deformations corresponding to the generating shape might be visible in the cloth under raking light imagery [3,5].

III. METHODS AND MATERIALS

The foldmark examination will consist of three phases.

1. The first involves examining the storage configuration of the Shroud with particular attention upon stress, temperature [6], and moisture. Photographs will be taken of the removal and unfolding process.

2. The second should occur soon after the Shroud is available for testing so that fabric strains due to mechanical or gravitational stresses do not obscure delicate foldmarks. The Shroud will be first placed on the 1978 testing frame in a horizontal position without stretching to allow tensional stresses in the deformed regions to maximally form the foldmarks. Visual examination of the "Mandylion-like" foldmarks will commence. This will be done with fixed off-normal illumination and hand-held illumination to give foldmarks greatest visibility by shadow formation. A hand-held camera will document the examination process and each investigator will record personal notes. Items to be examined include (1) locations of foldmarks, (2) directional structure of foldmarks, (3) propagation character- istics of foldmarks into 1532 fire patchwork and backing cloth, (4) reflectance variation of body image and background cloth across foldmark (for age estimation of the foldmark), (5) possible fracturing of blood images in foldmark, (6) waterstain intersections of foldmark, (7) possible directional changes along widthwise foldmarks, (8) evaluation of relative curvature of foldmarks (9) determination of temporal ordering onto the Shroud of the foldmarks with respect to the body and blood images, and (10) miscellaneous artifacts (possibly associated with Wilson's Mandylion hypothesis) as suggested by Wilson. Next, a visual examination pertaining to other possible foldmarks not observed in the 1978 testing will be conducted in a manner similar to the above. Particular attention will be given to the random creases known to cover the entire Shroud and how they intersect the body image. As discussed above, mechanical disruptions in the many random crease propagations due to possible stiffening by hypothetical image coatings on fibers will be studied. Following the front examination, the Shroud will be secured and the frame tilted to a vertical position and the back panels removed. Inspection of the backing cloth for corresponding foldmarks will be noted and photographed. The data collected in phase one will then be studied at a location away from the Shroud test area and folding configurations consistent with the data will be determined by models and computer analysis. We will then determine the procedures for subsequent study and documentation in phase three.

3. The third phase of the examination should occur two days or later after the first and second phases so that sufficient time for discussion can

occur. The first item for study will be direct follow-on examinations suggested by the Phase Two Data. If other artifacts associated with a given folding configuration are discovered, these will be documented. If certain stitchings are believed to be associated with a folding configuration or there are critical patches through which folds propagate, we will recommend their partial removal for C-14 dating [1].

Following these studies, general and specific documentation photographs will be made as per on site direction. These will include:

a. Oblique lighting photographs and electronic data capture imagery, (as discussed in a separate work package [7]), with even illumination along the two perpendicular axes of symmetry. Nonuniformities in illumination, if judged significant, will be removed by subsequent computer image processing. This will document any lengthwise and widthwise foldmarks. The Shroud will be in a vertical position.

b. Closeup stereo photographs of important foldmarks.

c. Photomicrographs of foldmarks at the intersections of blood, image, watermark, cloth, and patchwork regions. This will document observations made during phases one and two.

d. General documentation photography by a portable camera.

e. General stereo photographs of Shroud's surface. These photographs will be sent to the Biostereometrics Laboratory in Dayton, Ohio for computer reduction. This laboratory will provide us with computer xyz coordinates of the Shroud's surface for documentation and subsequent studies, if needed. We shall also correlate these characterizations with stereoradiographic imagery of foldmarks [8].

IV. EQUIPMENT IN TURIN

1. 1978 Test Frame
2. Illumination sources (with power supplies)
3. Cameras
4. Film
5. HP-85 microcomputer
6. Binocular Microscope with camera attachment plus stand
7. Magnifying glasses
8. 1978 Camera rail

V. TIME REQUIRED

A. Pre-Shroud in Turin:

B. On-Shroud in Turin:

(a) Phases one and two - 6 hours (in two, three hour blocks)

(b) Phase three - 10 hours

1. Followup examination - 2 hours
2. Oblique lighting - 2 hours
3. Closeup Stereo - 2 hours
4. Photomicrography - 2 hours
5. General Documentation photography (concurrent with 1.)
6. General Stereo - 2 hours

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FORENSIC WOUND RECONSTRUCTION and EXAMINATION OF TRACE EVIDENCE on THE SHROUD OF TURIN

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San Diego County Coroner's Office

COINVESTIGATOR: Keith Inman
Forensic Sciences Services

I. OBJECTIVE

A. Historical - (1) To reconstruct the event that produced the Shroud image by considering it as a crime and examining it from a forensic point of view, including an analysis of the bloodstains for wound patterns, the collection and examination of trace physical evidence, and drawing conclusions based on forensic reconstruction principles. (2) To conclusively determine if blood is present in the image areas of the Shroud using standard forensic techniques.

B. Conservation - To recommend storage and preservation techniques based on whether blood is present and the extent to which contamination has taken place.

II. STATEMENT OF THE PROBLEM

There are two major areas of inquiry on the Shroud of Turin with regard to an examination of its physical properties. The first is concerned with the reconstruction of the sequence of events that lead to the pattern of images seen on the Shroud, while the second is determining the nature of the material that forms the image. This proposal intends to extend further the work that has already been done in both [1-5] areas, using the precepts and principles of forensic science.

In order to use the principles of forensic investigation, it is necessary to assume that the Shroud covered a human body. The testing of this assumption, however, will be deferred to other investigators of this proposal set [7-9], as well as to some studies of this work package. The scope of the study is therefore restricted to determining, to the extent possible, the probable scenario which lead to the observable image properties on the Shroud. Thus, the problem is to derive a self-consistent model of the events depicted on the Shroud pictorally, chemically, physically, and microscopically.

A. Reconstruction of the event - Our forensic reconstruction falls into two categories: (1) an examination of the physical evidence alone and attempting to say as much about the event as possible (a description of the wounds, the device inflicting the wounds, sequence of events, description of the perpetrator, etc.); and (2) testing a story by examining the physical evidence for items that should be there if the event occurred as related.

Both of these approaches have limitations. However, when these limitations are acknowledged and respected, useful information can be

rived. Both use the same corpus of material as their testing grounds, e, the physical evidence. There is no substitute for the thorough :amination of the Shroud for trace and biological evidence as one of the ans for performing a reconstruction.

It is proposed that

1. A detailed examination be made of the bloodstain areas which seem to reflect specific injuries to the skin. The examination would attempt to discover if the shape, morphology, and other characteristics of the wounds could be delineated. This, in turn, would lead to an interpretation of their probable cause.
2. A general categorization of the types of trace physical evidence present.
3. The proposed hypothesis that the Turin Shroud is that of Jesus will be used as a guide in searching for specific items of trace evidence linked to the Crucifiction (the significance of such items if found or not will be determined after the examination and based on the quality of the data collected). These items include:
   a. blood (the result of wounds inflicted - Mt 27:26; Jn 19:1)
   b. botanicals from the crown of thorns (Mk 15:17; Jn 19:2)
   c. epithelial cells from the excoriations left by the scourging (Mt 27:26; Jn 19:1)
   d. fibers from a purple or scarlet robe (Mt 27:28; Mk 15:17; Lk 23:11; Jn 19:2)
   e. traces from a reed in his right hand (Mt 27:29)
   f. saliva from his face (Mt 27:30; Mk 14:65; Mk 15:19)
   g. acetic acid on his lips (Mt 27:48; Mk 15:36; Lk 23:36; Jn 19:29)
   h. soil from the tomb (Mt 27:60; Mk 15:46; Lk 23:53; Jn 19:42)
   i. myrrh and aloes (only Jn 19:39 makes references to actually applying the spices - all other accounts have Mary preparing the spices but never applying them)
   j. hair from the decedant

Given the history of the Shroud (noting that reports exist of attempts :o obliterate the image), some, if not all, of the above evidence may be ıbsent, even if originally present. Nevertheless, a thorough examination of :he pertinent portions of the Shroud is warranted. It is also important to :ry to establish what is present as contamination, and what is present as a result of the event in question.

There are several ways of examining an object for trace evidence. These include a visual inspection, ultraviolet and infrared light, tape lifts, microscopic examination, vacuuming, and photography. Daylight, UV, and IR photography have been performed on an overall and close-up scale but not microscopically. Tape lifts, however, do not allow an examiner to see the relationship of the evidence to the Shroud.

It is proposed that the Shroud be examined with a low power microscope (up to N30X magnification) to perform 2 and 3 above. If such evidence as may be helpful is located by this fashion, it would be photographed,

sketched, and removed with a pair of forceps (or via micromanipulator [7]) for later laboratory analysis. These techniques would disrupt the image even less than the tape lift method, and are selective. In addition, various non-image areas would be examined to determine the extent and type of contamination.

It is also proposed that the known environment of the Shroud (rooms, storage receptacles) be sampled so that an understanding can be gained of possible, current sources of contamination.

The examination of the items collected in this way is, with the exception of the blood, difficult to anticipate. However, the same forensic principles of individualization and identification would be used to characterize the evidence. In addition, valuable information would be gathered on the possible sources of contamination which would aid in interpreting the results of material gathered from the image areas.

All of the analytical information generated would be used to perform the two types of reconstructions as outlined above. This would consist of an evaluation of the significance of the evidence found, given its various environments, coupled with a testing of the Biblical account by looking for associated items.

If blood is present on the Shroud, the presence of bacteria must be considered, and preservation techniques can be recommended based on this finding, as also discussed in other work packages [7,10,11,12].

B. Examination of the Blood Particles - While the tests performed for the blood constituents by Heller and Adler [2] were numerous, they do not completely satisfy forensic requirements for the demonstration of the presence of blood, but rather are suggestive that further, more definitive, tests, should be run. We propose to undertake the completion of the earlier blood work by performing the following examinations:

1. Basic forensic hemoglobin color tests - Heller and Adler [2] report positive reactions with bromothymol blue and bromocresol green, both of which react with albumin. In addition, their hydrazine and ammonia hydroxide/potassium cyanide tests react to form hemochromagens. If these tests were positive, then other color tests should also be run, specifically using the reagents o-tolidine, phenolphthalein, and leuco-malachite green. These reagents all react with heme to form a hemochromagen, and are extremely sensitive as well as specific. Some authors contend that these tests, when run properly and in tandem, are absolutely specific. However, the best use of them is still presumptive, indicating that additional tests should be done (as discussed below in another work package [7]).
2. Conventional, immuno, and SDS electrophoresis for blood proteins - Heller and Adler [2] report positive reactions for albumin and hemoglobin (by inference). A direct way of visualizing blood proteins is to subject them to various electrophoretic procedures (see also Adler and McNeil work package [7]).

   The first one to be attempted would be a conventional discontinuous electrophoresis separation according to Ornstein and Davis [13,14]. It is expected that little

information would be garnered from this examination. However, it would give some useful information on the sensitivity of the electrophoretic technique, the extent of degradation of the sample, and information for future runs.

The second electrophoretic technique to be used would be SDS (sodium dodecyl sulfate) electrophoresis. This technique would give molecular weight information about the material, and be virtually conclusive about the presence of blood if hemoglobin (75% of total blood protein) and albumin (12% of total blood protein) were found.

The third technique to be employed would be adding an immunological step to an electrophoretic technique. Conventional discontinuous electrophoresis as in technique 1 above combined with an immunological staining procedure (using anti-human hemoglobin and/or anti-human albumin) would prove conclusively the presence of human blood. Sensitivity can be enhanced, if needed, by using an antibody that has been radioiodinated. A different approach would be to use a conventional immunoelectrophoretic technique. This consists of an electrophoretic separation followed by passive diffusion of an anti-human serum. (If successful, it would also constitute positive proof of the presence of blood). This technique, however, is limited by its sensitivity. Cross-over electrophoresis as another technique is discussed below.

3. Standard immunological techniques for blood proteins - It is proposed that three immunological tests be run.

The first would be the precipitin test. An extract of the blood material is layered over a specific anti-human serum. A positive reaction is virtual proof of the presence of human blood.

The second would be a cross-over electrophoretic technique. Here the proteins are forced to migrate toward each other in an electrophoretic field.

The third test to be run would be an immuno double diffusion method. This method is superior to the above two tests in that specificity is greater. However, sensitivity is reduced.

The major problem with all of the electrophoretic and immunological tests would appear to reside not in the quantity of material needed (since Heller and Adler [2] had solid (albeit small) chunks of material with which to work). All of the above tests have been developed to work on microscopic particles and low dilutions of blood. Rather, the major unknown is the extent to which time has destroyed the antigenicity and native biological properties of the blood proteins. If the tests performed by Heller and Adler [2] were truly detecting hemoglobin and albumin, then some, if not all, of the tests outlined above should work.

4. GC-MS of bilirubin - Heller and Adler [2] used a color reaction to detect bilirubin. It is proposed that a sample

of the blood be extracted and run on the GC-MS (Gas chromotgraph-mass spectrometer) to detect bilirubin and other hemoglobin breakdown products. The GC-MS gives both chemical and structural information on molecules; a positive result on this instrument would give conclusive proof that bilirubin is present.

III. MATERIALS AND METHODS

Close-up, high resolution photography would be done on each bloodstain area in both color and U.V. In addition, visual and microscopic examination of each stain would be done to get a better concept for the stains, the substrata, and their relationship to one another.

The Shroud will be placed on the 1978 testing frame in a horizontal position. Various portions of the Shroud (image and non-image areas, top side and underside) will be examined with a stereomicroscope (7x-30x). Some portions of the examination would be performed using a hand-held ultraviolet light. Any item of trace evidence seen that warrants removal (blood particle, hairs, fibers, botanicals) would be photographed, sketched, and removed with a pair of forceps into appropriate evidence containers.

Tape lifts or micromanipulator [7] extracts may again be taken from a few areas to acquire trace evidence that would require a high power microscope (which is unsuitable for searching) for detection.

Visible lighting for the microscopic examination would be by flexible fiber-optics, which generates no significant heat and thus would not degrade the fabric.

The underside portion of the Shroud would also be examined microscopically. The types of trace evidence present would be noted, and some would be removed as above for later examination.

The contents of the examining room would be noted, and exemplar samples would be taken from some of them. This would again be microscopic samples. The taking of these samples will not interfere with their integrity nor be observable by the naked eye.

The object in which the Shroud was normally stored (be it box, bag, a room, etc.) would be vacuumed using a portable vacuum to which is attached a trace evidence collecting device. Again, this will not interfere with the integrity of the object nor leave any observable traces to the naked eye behind.

The remaining analytical examinations will be performed in Los Angeles, California.

IV. EQUIPMENT

A. In Turin

1. 1978 Shroud test frame
2. Visible and ultraviolet illumination sources (with power supplies)
3. Camera
4. Stereoscopic zoom microscope (7x-30x), binocular, plus stand, with photomicrograph capabilities
5. Film
6. Trace evidence implements (forceps, proble, etc.)
7. Evidence containers (pillboxes, bindles, glass vials, petri dishes, etc.)

8. Sticky tape

B. At home - laboratories equipped to do biological and instrumental analysis.

TIME REQUIRED

A.	Pre-Shroud in Turin:	2 hours
B.	On-Shroud in Turin:	
	Photography of bloodstain areas:	6 hours
	Top side:	12 hours in 3-4 hour sessions
	Underside:	2 hours
C.	Environment	4-8 hours, depending on extent, variety of environment
D.	Post-Shroud in Turin:	4 hours
E.	At home:	1000 hours

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INFRARED INVESTIGATION OF THE TURIN SHROUD

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I. OBJECTIVES

A. Determine the thermal characteristics of the Shroud and its image.
B. Determine the thermal environment in which the Shroud is permanently stored for conservation related studies.
C. Provide temperature measurement support as required for other experiments.
D. Obtain IR Spectral data of the Shroud and its images.

II. STATEMENT OF THE PROBLEM

Temperature is a basic thermodynamic property and one which can be measured by remote sensing since all physical objects emit electromagnetic radiation. At room temperature the primary wavelengths emitted are in the infrared region of the spectrum. We propose to extend the earlier work of Accetta [1] who obtained thermographic images and infrared spectra from the Shroud image. The infrared studies we propose are as follows:

A. Determine the thermal characteristics of the Shroud and its image.

Based on chemical studies from the 1978 testing, it appears that the Shroud image is a cellulose degradation [2]. Although there are various ways cellulose can be degraded (e.g., chemically, photolytically, etc.), it is possible to do so by heat. It is also known that the body image resides on the cloth surface [3,4], a characteristic consistent with a limited heating time (if heat was involved to produce the image). Accordingly, we propose to measure the thermal diffusivity, D, of the Shroud cloth across its thickness and along its threads and fibrils to support studies involving heat-based image formation mechanisms. To measure D across the thickness, we shall place a uniformly warm (several tens of degrees above ambient) large thermal mass at the back surface of the Shroud (preferably inserted between the backing cloth and Shroud) and digitally record the thermal image at the front surface as a function of time. Comparison of the temperature rise with theory for the one-dimensional heat flow solution where one boundary is held at a fixed temperature will provide a numerical value for D

2X-1

across the thickness. (Laboratory experiments indicate that this process takes place on the order of several seconds). We shall also apply this uniformly heated mass to the front surface to raise the temperature above ambient to see if variations in emissivity between image and cloth can be detected. We also propose to moisten the Shroud with distilled water in a small 3 cm x 3 cm corner region and repeat the above measurements to determine D for the Shroud with elevated water content.

A similar experiment will be performed at high magnification to measure D along threads and fibrils. A uniformly warmed thermal mass will be placed upon the cloth front surface and the migration of temperature into adjacent threads and fibrils will be observed microscopically and recorded as a function of time and position. Of interest will be how the weave pattern affects lateral heat flow and how temperature is transmitted from fibril to fibril (important since it has been reported that where colored fibrils twist below other colored fibrils there is no evidence of coloring; this might be difficult to explain if good thermal contact is observed in such fibrils). The above characterizations of D will provide basic data concerning the Shroud's heat flow properties, both macroscopically and microscopically. In no case will the temperatures be such as to thermally discolor the Shroud.

Finally, we propose to extend Accetta's thermographic work [1] to cover the entire Shroud. By illuminating the Shroud in sections with a visible lamp, the infrared temperature image of the Shroud (i.e. image, blood, scorches, clear cloth, and waterstains) will be recorded.

B. Determine the thermal environment in which the Shroud is permanently stored for conservation related studies.

The Shroud has been maintained in a special box for a long time. Since (1) temperature governs the rate at which cellulose aging by oxydation occurs and (2) the Shroud probably undergoes a sudden temperature change when removed, we propose to observe the initial equilibrium Shroud temperature distribution and its subsequent change with time immediately after the box is opened. We propose to record the temperature distribution on the Shroud in its initial rolled configuration and as it is being unrolled. The observation process will continue until the Shroud cloth has reached thermal equilibrium with its new environment. From these data we shall evaluate the thermal conditions of storage and the thermal stress associated with removal.

This data will be coordinated with the Conservation work package [5].

C. Provide temperature measurement support as required for other experiments.

In another work package [6], it is proposed that the Shroud be artificially aged in situ by low power laser radiation. In this experiment, temperature must be monitored. This will be accomplished via the infrared thermography instrumentation described herein.

D. Obtain IR Spectral data of the Shroud and its images.

Accetta [1] obtained infrared spectral data from the Shroud. However, these data were judged to be somewhat inconclusive. Accordingly,

we propose to extend and perhaps improve upon the spectral data so as to provide spectral information concerning the Shroud in the infrared.

III. METHODS AND MATERIALS

A Texas Medical Instruments, Inc. Thermiscope is presently available to the investigators for the performance of this examination; however, it is anticipated that an advanced version of the Thermiscope will be available by the time the actual examination occurs. The advanced version, the Thermiscope-D, provides the normal high-quality Thermiscope thermogramic imagery in a digital format. Image data will be stored on either floppy disks or digital tape. The image format will be 512 by 512 pixels with 10-bit words. In addition, the signal processing power of the Thermiscope-D will allow the averaging of a number of frames of the same area of the Shroud thereby yielding significantly better thermal sensitivity. The thermal sensitivity of the Thermiscope-D will be 0.05 K. The Thermiscope is capable of providing up to approximately 20 lines pairs per inch spatial resolution when the field-of-view at the Shroud is about 1.2 sq. ft. A valuable characteristic of the Thermiscope for this experiment is its wide field-of-view with high spatial resolution (over 262,000 pixel per image). This therefore allows observation of larger segments of the Shroud within a single image. In addition, a similar but different Thermographic instrument, an AGA 780 system, with capabilities of digital recording and magnification IR microscopy via close-up extension rings will also be used. The temperature sensitivity is 0.1 K with 128 by 128 pixels of information obtained in each 1/25 of a second. This will provide two complimentary thermographic instruments, one of which will be used extensively in the artificial aging work package [6]. In addition, the use of two thermographic instruments would be invaluable in measuring the real-time temperature distributions on the Shroud as it is removed from its reliquary and unrolled.

Using a Thermiscope-D, the image data will be recorded digitally with a dynamic range large enough to contain all experimentally significant information while maintaining system sensitivity; thus, the operator does not have the burden of carefully selecting the correct dynamic range. By recording the data in this manner, we will be able to reduce the data using normal image processing techniques to obtain Shroud images with a quality level surpassing those obtained heretofore. For example, the data contained within a specific image can be examined by a computer or image processor to determine the distribution of information within the recorded dynamic range. The investigators can then use this result to explore the content on the image. The pictorial presentation of the data is monochrone for the Thermiscope while the Thermiscope-D offers in addition "false" color. As a result of the data being in a computer readable form and because the Thermiscope is an imaging radiometer (absolute measuring device), high quality mosaic images of large sections (or of the entire shroud) should be realizable. A further advantage of having the data acquired and stored in this form is that it is easily transportable to other investigators without having the issue of loss of data quality due to handling etc. being raised. In addition, the value of having an absolute radiometric instrument to

acquire the image data is that the data will be consistent over the entire Shroud area.

Infrared spectroscopy, using equipment similar to Accetta [1], will be used to provide information regarding the molecular structure of the body image and foldmark regions (complimenting the x-ray diffraction work [7]). This approach employs a low bandwidth spectral reflectometer with infrared illumination source. Another interesting method of obtaining new infrared reflectance spectrographic data will be to incorporate into the Thermiscope an infrared circular variable filter to allow the acquisition of high quality spectral images of the Shroud. From these spectral images, "true" color image representations will be produced. This is in contrast to the more common "false" color representations used in the thermographic industry.

IV. EQUIPMENT

1 - 1978 Shroud Table
1 - Thermiscope with optional equipment
2 - Polaroid Cameras and necessary film.
Liquid Nitrogen
Spectral reflectance instrumentation
1 - 1978 camera rail

V. TIME REQUIRED

A. Setup in Turin 24 hours
B. On Shroud in Turin 12 hours (2 blocks of 6)
Objective A - 5 hours
Objective B - 1 hour
Objective C - as required-accounted for in other work packages
Objective D - 6 hours
C. Off Shroud 2 hours
D. At home 500 hours

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ISOTOPE RATIO MEASUREMENTS OF OXYGEN AND HYDROGEN FROM THE CELLULOSE OF THE SHROUD FABRIC

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I. OBJECTIVE

We propose to remove a small sample from the Shroud for mass spectrometric analysis. Measurements of the isotope fractions $^{18}O/^{16}O$ and D/H ($^{2}H/^{1}H$) from the linen cellulose should provide information about the climate where the flax was grown. The new data will test competing hypotheses on the geographical origin of the Shroud.

II. STATEMENT OF THE PROBLEM

The Shroud of Turin has been the subject of continuing controversy throughout its known 600 year history. A major issue concerns its origin. No one really knows how old the Shroud is or where it came from, but opinions differ sharply nonetheless. Some think the Shroud was the actual burial cloth of Jesus. Proponents of authenticity believe the cloth was manufactured in or near Palestine during the early first century. Opponents of this position refer to a letter written in 1389 by Pierre d'Arcis, Bishop of Troyes. In it the bishop states that his predecesser had conducted an investigation into the matter and had actually turned up an artist who confessed to the forgery. In the opponent's view, the Shroud is a product of European technology of the early 14th century. While these opposing positions in no way exhaust all possibilities, they have nonetheless remained predominant. It therefore seems appropriate that some experiments be designed to test one hypothesis against the other.

So far, the available physical information remains largely inconclusive. Raes [1] observed that neither thread-twist nor weave type are sufficiently distinctive to locate the origin of the fabric. However, he did find small traces of cotton (G. herbaceum) fibers included in the linen threads. This observation suggested to him that the linen may have been spun with the same equipment used previously for cotton. The cotton inclusions support a Middle-East manufacture, but they do not prove it. A second piece of evidence supporting authenticity is offered by the pollen studies of Frei [2]. However, this work is inconclusive because of its lack of control studies and detailed descriptions of experimental procedure.

Origine geografica

Finally, we note that, of all the observations and data collected in 1978 [3], none bear directly on the question of the age of the Shroud or its geographical origin. In this proposal set, both questions are being addressed. A proposal for radiocarbon dating is presented separately [4]. Here, we describe measurements of the hydrogen and oxygen isotopes of the cellulose. This information should help determine the geographical origin of the fabric.

The Shroud is a linen textile; its threads consist of cellulose fibers derived from flax. The cellulose itself is a polymeric compound of hydrogen, carbon, and oxygen. Each of these constituent elements exists in several stable isotopic forms. The lighter isotopes ^{1}H, ^{12}C, and ^{16}O are generally more abundant, but smaller concentrations of the heavier D (^{2}H), ^{13}C, and ^{18}O are also found in measurable amounts. In any given sample the relative quantities D/H, $^{13}C/^{12}C$, and $^{18}O/^{16}O$ vary depending on the physical and chemical history of the material [5].

The isotopic composition of cellulose is known to be influenced by the temperature and humidity of the growing environment. Climate affects isotope ratios in at least three ways. First, the cellulose composition reflects the isotope concentration of the local precipitation [6]. In general, the ratios $^{18}O/^{16}O$ and D/H in rainwater decrease with decreasing temperatures. Lower relative quantities of the heavier isotope are found in meteoric water at higher latitudes, greater distances from the ocean source, and higher altitudes [7]. The isotope composition of cellulose is related somewhat indirectly to temperature by this process, but the dependence has been empirically demonstrated for both carbon-bound D/H [8,9], and $^{18}O/^{16}O$ [10] in tree cellulose.

The second significant influence is the humidity of the growing environment. Photosynthesis in terrestrial plants takes place in transpiring leaves. Evaporation tends to concentrate the heavy isotopes in the leaf water; the lighter component $^{1}H_{2}{}^{16}O$ evaporates more readily because of its higher vapor pressure. Environments with lower humidity promote the evaporative-transpiration process, and arid climates produce plant cellulose with greater relative fractions of deuterium and ^{18}O. The measurements of Dongman et al. [11] demonstrate this effect for ^{18}O in leaves as a function of time over a 48-h period. Similarly, the data of Epstein et al. [12] are now best explained by this process where the enrichment of ^{18}O is relatively greater than that of D as one might expect.

A third important process is the isotopic fractionation that accompanies biosynthetic reactions in plants. Hydrogen and oxygen are incorporated into cellulose by a series of steps that result in net

depletions of deuterium [13] and net enrichments of ^{18}O [14,15] relative to the source water. The details of these reactions are not well understood [15]; fractionation apparently proceeds differently in different modes of photosynthesis. However, experiments have shown that $^{18}O/^{16}O$ relationships between cellulose and source water are similar in all plants and are generally independent of temperature [14,15]. In contrast, hydrogen isotope fractionation during cellulose formation is quite variable among species and shows large temperature dependences [14], sometimes in surprising and unexplained directions [16].

With proper control studies, the isotope ratios in cellulose can be used as reliable indicators of the growth climate of plants. Brenninkmeijer et al. [17] measured variations in D/H and $^{18}O/^{16}O$ in cellulose extracted from a peat bog core. These data taken as paleoclimatic indicators agree qualitatively with pollen analyses of the material. We are suggesting that similar isotopic analyses of the Shroud material will provide information about the climate where the flax was grown. A cooler, more humid climate like that of Europe should produce lower relative concentrations of the heavier isotopes in the cellulose than would the warm, arid environment of the Middle East. This experiment should provide the first unambiguous physical evidence bearing on the question of the geographical origin of the Shroud of Turin.

III. METHODS AND MATERIALS

Isotope measurements of the Shroud material can only be understood in the context of a reasonably broad data base. The initial step in our research program is to conduct a series of control studies. In view of the critical influence of biosynthetic fractionation, one of the first experiments will be to compare the hydrogen and oxygen isotope ratios from cellulose of the same species of flax grown under the two different climate conditions. Both field and laboratory experiments will be undertaken to establish the range and variability of the effects. All of the investigators will be active in this initial phase. Next, we intend to carry out similar measurements on cellulose from textiles and papers from both Europe and the Middle East and from different time periods. Materials for this work are being drawn from various museum study collections. Druzik has assumed primary responsibility for their procurement, and DeNiro will perform the analytical measurements.

The next step will be to remove [18] about 60 mg (3 cm^2) of fabric from one edge of the Shroud. The remaining work will be done in DeNiro's mass spectrometry laboratory at the University of California at Los Angeles. The sample will first be cleaned with NaClO and NaOH solutions to remove any lignins, hemicellulose, or cellulose decomposition products that may be present. The cleaned sample will then be divided into two parts. One portion will be taken for the $^{18}O/^{16}O$ measurement, the other for the D/H.

Epstein et al. [13] showed that only the D/H ratios of the carbon-bound hydrogen hold any significant information about the growing climate of the plant. Hydrogen associated with the OH groups must first be removed. Standard procedure for removal of the exchangeable oxygen-bound hydrogen is

to treat the cellulose with a mixture of nitric acid and acetic anhydride. The cellulose nitrate product is then combusted and the water reduced to H_2 gas for mass spectrometric analysis.

Oxygen is extracted from the cellulose by heating the sample in a closed evacuated nickel vessel at 1100°C. The H_2 gas formed diffuses from the vessel through its heated walls and into the atmosphere. The technique converts the cellulose oxygen into CO and CO_2. The CO is then isolated, oxidized to CO_2, and finally recombined with the original CO_2. The total CO_2 sample is analyzed mass spectrometrically. These methods of sample preparation and measurement are standard techniques that have been used successfully in DeNiro's laboratory during the past three years.

IV. EQUIPMENT

All the analytical equipment necessary for this experiment is available. The sample will be removed in accordance with the direction of the Turin authorities.

V. TIME REQUIRED

A.	On-Shroud in Turin:	2 hours
B.	Post-Shroud in Turin:	1 hour
C.	At home:	400 hours

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5. Heavy isotope concentrations are typically expressed as per mil deviations from an appropriate standard value. Earlier, results for hydrogen and oxygen were given relative to corresponding SMOW (Standard Mean Ocean Water) values established by H. Craig [Science 133, 1833 (1961)]. New, more precise standards have since been adopted [see R. Gonfiantini, Nature 271, 534 (1978)] and are referred to with the subscript V-SMOW. Isotope fractions are presented in the so-called δ notation. To illustrate this convention, we calculate for a measured sample value of oxygen, $(^{18}O/^{16}O)_{sample}$

$$\delta^{18}O = \left[\frac{(^{18}O/^{16}O)_{sample}}{(^{18}O/^{16}O)_{V\text{-}SMOW}} - 1 \right] \times 1000$$

where $(^{18}O/^{16}O)_{V\text{-}SMOW}$ = 2005.20 ± 0.45 ppma (atomic parts per million). Similarly, for hydrogen the analogous expression would be used but with $(D/H)_{V\text{-}SMOW}$ = 155.76 ± 0.05 ppma in the denominator of the bracketed term. Typical experimental uncertainties are ± 0.2 and ± 2 per mil for $\delta^{18}O$ and δD, respectively.

6. This is equally true for both oxygen and hydrogen. Terrestrial plants derive oxygen for cellulose production from both water and atmospheric carbon dioxide [A. Stemler and R. Radmer, Science 190, 457 (1975)]. There was some concern that measured $\delta^{18}O$ values in cellulose would to some extent reflect the isotopic composition of the CO_2. Bottinga and Craig [Earth Planet. Sci. Lett. 5, 285 (1969)] found that atmospheric carbon dioxide has a $\delta^{18}O$ of 41 per mil, an amount that is nearly uniform worldwide. However, DeNiro and Epstein [Science 204, 51 (1979)] have shown that water and carbon dioxide within the plant undergo complete equilibration of their $^{18}O/^{16}O$ ratios by the time the cellulose is fully synthesized. Water is available to the plant in much larger quantities than is carbon dioxide. The observed equilibration process, therefore, assures that isotope ratios in cellulose indeed reflect that of the environmental water.

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LARGE FORMAT COLOR PHOTOGRAPHY AND VIDEO DOCUMENTATION

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B. M. Schwortz
Barrie Schwortz Studios

I. OBJECTIVE

A. Large Format Photographic Documentation: To photograph in high fidelity color and with better detail than that obtained in 1978, all the important features of the Shroud image such as face, eyes, hands, blood stains, and skin wounds. It is also proposed to photograph as much of the back side of the Shroud as is possible. These photographs will be produced on 8"x10" color transparency film at magnifications from scale (1:1) to reductions of the full image on a single film.

B. Video Documentation: To record the entire investigation in "real time" video. Special attention will be placed on those tests and experiments requiring close inspection (i.e., fibril excision, etc.).

II. STATEMENT OF THE PROBLEM

A. Large Format Photographic Documentation: In 1978, the major photographic effort was to provide spectrally distinct photographs for computer analysis [1]. Because of their small size and absent color component, these photographs are not ideal for visual inspection and evaluation. By virtue of the stated needs, little emphasis was given to color photography in 1978. However, a few color photographs were made for documentation purposes. These have been extremely useful in the analysis of the image characteristics, and demonstrate the need for detailed coverage. Large (8"x10"), full color, transparencies will provide a lasting, color faithful record of the most subtle details on the Shroud. In addition to reflectance imagery of the front surface, large format color photographs of the backing Holland cloth, transmitted light photographs of the Shroud, and as much of the back side of the Shroud as possible will be taken. This will compliment the imagery and data associated with work packages [2], [3] and [4].

B. Video Documentation: Although careful records and still photographs were used to document the 1978 investigation [5], the recollection of many of those involved differ to some extent. Video

recordings with audio of the entire sequence, from set-up to tear down, will provide an accurate, minute by minute, record of the event.

III. METHODS AND MATERIALS AND EQUIPMENT

A. An 8"x10" view camera with electronic flash heads spaced equidistant will be attached to the camera support and optical rail as in 1978 [1]. The rail will then be aligned with the examination table to eliminate perspective distortion and focus errors. After alignment, the camera support can be moved to predetermined indices on the rail to provide evenly spaced, overlapping photographs of the entire cloth at magnifications of 1:1 to 1:168.

We also request that as much of the backing cloth be removed (and if possible all of it) so that the back side of the Shroud can be inspected and photographed.

B. Two fixed, 1/2" surveillance Video Cassette Recorders (VCRs) in continual operation, will provide the overall coverage. In addition, high quality, 3/4" mobile video cameras will be directed to cover all the important experiments and discussion sessions [6].

V. TIME REQUIRED

A. Large Format Color Photography

On-Shroud in Turin:	1:1 coverage, 160 images x 2 for front surface reflectance and transmission and rear surface reflectance imagery	14 hours
	Reductions, 12 views	3 hours
	Body features, 12 views	3 hours
	Back side of Shroud (including stitching time)	8 hours
	TOTAL	28 hours

In U.S. - 20-40 hours preparation: 2 months processing and evaluation

B. Video Documentation

On-Shroud in Turin: 6 hours set up. Will be accomplished before Shroud is delivered for examination. Once surveillance cameras are placed, the investigation need not be interrupted. Detailed documentation as requested with minimal effort.

In U.S. - 20-40 hours preparation: 2 months processing and evaluation

VI. REFERENCES

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MICROBIOLOGICAL ANALYSIS
FOR ON-SITE CONSERVATION STUDIES OF THE TURIN SHROUD

PRINCIPAL INVESTIGATOR: William J. Cairney, Ph.D.
United States Air Force Academy

COINVESTIGATOR: To be Determined (one additional)

I. OBJECTIVE

To evaluate the effects of microbiological action on the Shroud of Turin and its images.

II. STATEMENT OF THE PROBLEM [1]

A prime concern of all custodians and research investigators of the Shroud of Turin is indefinite preservation of the cloth. While the Shroud may have been kept free of moisture and dust for many centuries, recent interest in the Shroud has resulted in longer and more frequent exposures. With more manipulation and exposure to airborne microbial propagules, it is conceivable that the cloth may be harboring organisms (especially fungi) which might ultimately lead to degradation of the cloth, hence degradation of the image, rendering the shroud less able to yield useful quantitative and qualitative information. To our knowledge, the Shroud has never been extensively examined for potential microbial processes. In this proposal, we investigate each of these areas and propose methods for preservation if required.

Since fungi are the microbial agents responsible for a large share of the disintegration of organic matter, special emphasis needs to be placed on isolation and systematic identification of fungal species. Food, leather, fabrics, and wood are especially susceptible to fungal degradation. Fortunately, fungal organisms which cause degradation of cloth are easily recognizable because they have distinct reproductive structures. Although our search for potential fabric-degrading species will be essentially unlimited, we will specifically search for Aspergillus spp., Penicillium sp and members of the Ascomycete family Chaetomiaceae. The Chaetomiaceae include several species capable of destroying cellulose. The genera Lophotrichus, Ascotricha, and Chaetomium (all in Chaetomiaceae) have been implicated in degradation of cellulose products (principally paper and fabrics) and are capable of causing considerable damage.

III. METHODS AND MATERIALS

The microbial examination will consist of two phases:

1. The Shroud will be visually examined using magnifying lenses and a binocular steroscopic microscope. The examination will include clear cloth, scorch, waterstain, body image and bloodstain regions. All areas of suspected microbial degradation will be noted and damage (even if minor) described and assessed.

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2. In areas of suspected microbial degradation, propagules of the organism(s) will be recovered on sterile "sticky" tape and transferred to microbial culture media. Culture media will include nutrient agar (standard bacterial maintenance medium); brain-heart infusion agar and yeast-extract-pepton glucose medium (for isolation and maintenance of bacteria with more fastidious nutritional requirements); and Sabouraud's dextrose agar, potato dextrose agar, and corn meal agar (for isolation and maintenance of fungi). As microbial colonies appear on initial culture plates, the organisms will be transferred to fresh media where they will be maintained in pure culture for subsequent identification. Adler and McNeil [2,3] have mentioned the problems of collecting materials from the Shroud without particular targets in mind (i.e., not really knowing what to expect by way of results or findings). This proposal, however, has a specific target, but materials collected may yield unexpected (or at least interesting) additional information. For instance, the procedure described will provide a nearly complete microbial analysis of the Shroud. These data will be collected and reported for whatever additional information they may yield. Coordination with the studies proposed by Riggi [4] and Druzik [5] will be made. A complete report will be given of the microbial flora and recommendations made for retardation and/or elimination of any organisms deemed harmful to the integrity of the cloth.

The cloth will not need to be removed, cut, or altered for this analysis.

IV. EQUIPMENT

1. Magnifying lenses
2. Stereoscopic binocular microscope, Binocular light microscope
3. Illumination sources (with power supply)
4. Sterile stick tape
5. Microbiological growth media
6. Glassware to include petri plates, test tubes with screw caps; microscope slides and cover slips
7. Standard microbial staining reagents, including Crystal Violet, Gram's Iodine, Acetone/Ethanol, Saffranin, Cotton Blue in Lactophenol, KOH, and Methylene Blue
8. Access to steam autoclave, incubators, bunsen burners and/or bacticinerators (note: if this equipment is not available or accessible in the Turin region, samples could be returned to the United States for processing. Ideally, however, the procedures should be carried out with as little time delay as possible).

V. TIME REQUIRED

1. Set up in Turin — 2 hours
2. On Shroud in Turin
   Part 1, visual microscope examination - 4 hours
   Part 2, sticky tape recovery of organisms from the cloth - 1 hour
3. Off Shroud in Turin
   Incubation, isolation, identification of microbial species - up to 1 man-week depending on complexity of identification procedures which become necessary as to the nature and identity of isolated species.

VI. REFERENCES

1. Alexopoulas, C. J. 1966. Introductory Mycology. 2nd Ed. John Wiley & Sons, New York.
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3. Heller, J. H., and Adler, A. D., "A Chemical Investigation of the Shroud of Turin", Can. Soc. Forens. Sci., J., Vol. 14, No. 3, 1981.
4. Microfauna and Microflora Identification on the Shroud of Turin - Riggi; Porrati; Mastropirro; Saverio, (Work Package) 1984 STURP Proposal.
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MICROBIOLOGICAL ANALYSIS OF IRON OXIDE DEPOSITS ON THE SHROUD OF TURIN

PRINCIPAL INVESTIGATOR: William J. Cairney, Ph.D.
United States Air Force Academy

COINVESIGATOR: To be determined (one additional)

I. OBJECTIVE

To determine if some iron oxide on the Shroud of Turin is of microbiological origin.

II. STATEMENT OF THE PROBLEM

In the extensive chemical analyses of the Shroud of Turin, iron oxide deposits have been noted. In one investigation, the researchers allege that the image was formed by painting iron oxide pigments bound with animal protein onto the cloth [1-3]. In another, it is suggested that iron oxide was deposited as an ion exchange process during retting [4]. This proposal advances an alternate hypothesis for the presence and distribution of oxide of iron on the Shroud of Turin.

The bacterial family Siderocapsaceae is known for producing oxides of iron as biproducts of a somewhat unique metabolism. These organisms are chemolithotrophic (i.e., utilize inorganic compounds as sources of energy). They represent a wide range of morphological types (some are spherical, others ellipsoidal or bacilliform). Some genera are completely autotrophic (able to synthesize all organic components from inorganic sources) while others are facultatively autotrophic (adjustable to whatever sources of energy may be present, from organic to inorganic). Genera of this family are generally found in fresh water and are usually imbedded in a viscous, mucilaginous capsule. All genera in the family Siderocapsaceae form magnesium and/or iron compounds and deposit them in the mucilaginous capsule. While the Siderocapsaceae appear to be distributed world-wide, they are especially prevalent in iron-heavy bogs, lakes, rivers, and streams of central and northern Europe. In fact, most of the type species have been isolated and described from that region. These organisms are frequently found in association with algae, forming zoogloeal masses [5].

We hypothesize the following scenario: It is known that the Shroud of Turin was involved in a fire while it was located in France. It is also known that the Shroud was soaked with water (in parts) in an effort to save the cloth. If the water used to douse the cloth were populated with Siderocapsaceae genera (especially if in combination with algae in a zoogloeal mass), the organisms would probably have continued to proliferate (to significantly large populations) until the cloth dried. These genera would have utilized inorganic iron from the water and/or organic compounds from the cloth to derive energy. As chemolithotrophs they would have been able to utilize even inorganic sources of carbon to maintain metabolic

activity. Significant is the fact that the iron oxide-containing capsular material (mucilaginous slime) produced in such abundance by these organisms is generally yellowish to brown in color. This is precisely the color of the pigmented areas on the Shroud presumably containing Fe_2O_3 [4]. The greatest build up of mucilaginous capsule would naturally have been in regions of the Shroud holding water the longest (i.e. creases and folds) or in regions containing materials capable of being metabolized by the organisms (e.g. human exudates, plasma proteins, heme proteins, etc.). We thus hypothesize that the presence and distribution of the iron oxide deposits are explainable on the basis of microbial action initiated by the drenching of the Shroud by water rich in members of the Siderocapsaceae. It is conceivable that microbial contamination could have affected the blood images, giving them a reflectance spectrum similar to Fe_2O_3 [6]. This, for example, might have been possible since some members of Siderocapsaceae are motile (i.e. mobile) which could have lead to general contamination of the Shroud blood areas from specific contamination sites. This process conceivably could have been aided by moisture (e.g. via subsequent wettings, steam vapor contamination from water contact with the heated silver box in 1532, or sufficient relative humidity in the atmosphere), cloth contact by folding or rolling, or excreted mucilaginous material (which acts as a transport medium) for the organisms.

III. METHODS AND MATERIALS

The microbial examination will consist of three phases:

1. The native water in the immediate vicinity surrounding the location of the Shroud when it was drenched will be analyzed for the presence of Siderocapsaceae genera. Special attention will be given to the presence and color of zoogloeal masses and pigmentation of capsular material in isolated genera. (Note: We acknowledge change of the native waters with time as a possible variable in this invesgitation. We postulate, however, that native streams, lakes, etc. would have largely retained their characteristic microbial flora, even over centuries, unless acted upon by industrial pollutants or large amounts of other input products).

2. While it would not be likely that viable Siderocapsaceae genera could be isolated from the Shroud (given the present dry state of the cloth and the length of elapsed time since the fire), capsular materials would have remained stable and could still contain dried cells. "Sticky" tape samples will be taken from areas of heavy oxide deposition. These samples will be gram stained for confirmation of the presence and types of organisms. Previous chemical analysis of the regions of greatest iron oxide deposition should be re-examined for the presence of known capsular components of bacteria (e.g., polypeptides of D-glutamic acid; dextran composed of glucose subunits; complex polysaccharides composed of rhamnose, glucose, glucuronic acid, galactose, and/or N-acetylglucosamine subunits; levan composed of fructose subunits; etc.) [7]. Iron distribution information provided by the x-ray fluorescence examinations [8,9] should be useful in selecting areas for sampling.

3. Cloth of similar composition to the Shroud will be soaked with water taken from the location of the Shroud in France when it was drenched.

The cloth will be allowed to dry and then examined for the presence of iron oxide, stains, and evidence of capsular/zoogloeal materials.

IV. EQUIPMENT

1. Vials for collection of samples (box of 24 four oz. jars with screw caps)
2. Sterile sticky tape
3. Microbiological growth media
4. Glassware to include petri plates, test tubes with screw caps, microscopic slides
5. Standard microbial staining reagents
6. Access to steam autoclave, incubators, bunsen burners and/or bacticinerators, Binocular light microscope with Kohler illumination. (Note: If this equipment is not available or accessible in the Turin region, samples could be returned to the United States for processing).

V. TIME REQUIRED

1. Part 1, Trip to France, interview with appropriate persons, visual survey of local streams, etc., obtaining water samples from "most likely sources" - 3 days. Incubation, isolation, identification of microbial genera - up to two man-weeks depending on complexity of identification procedures which become necessary. (The identification phase could be done in a stateside laboratory).

2. Part 2, "Sticky" tape sampling from Shroud - 2 hours; gram staining, analysis, examination of "sticky" tape samples - 1 man-day (could be done in stateside laboratory); review of previous chemical analyses - 1 man-week depending on nature of findings.

3. Part 3, Soaking and examination of Shroud-like cloth - 1 man-week (could be done in stateside laboratory if cloth were soaked in France and returned).

VI. REFERENCES

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9. X-Ray Fluorescence - B - Carter, Ph.D.; Jumper, Ph.D.; and Carriveau, Ph.D., (Work Package) 1984 STURP Proposal.

MICROFAUNA AND MICROFLORA IDENTIFICATION ON THE SHROUD OF TURIN

PRINCIPAL INVESTIGATOR: G. Riggi
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TECHNICIANS: G. Porrati (Electronic Tech)
M. Mastropirro (General Tech)
Turin, Italy

PHOTOGRAPHER: N. Saverio
Turin, Italy

I. OBJECTIVE

To carry out direct research in various areas of the Shroud for existing microfauna, whether alive or not, and to describe by accurate drawings the extent and intensity of their presence as well as the identification of the organisms.

II. STATEMENT OF THE PROBLEM

In October 1978, dusts were drawn and analyzed from 4 small areas (representing about 1/7 of the total surface) in the interspace between the Shroud and its supporting Holland cloth [1]. This allowed the formulation of a biological picture of the cloth that indicated the presence of large colonies of fungi and microfauna.

The planned tests on the biological activity of the dusts that were made originally allowed on one hand the singling out and the identification of fungi and bacteria but, on the other hand, did not permit a full evaluation of the presence of certain animalicula (mostly arachnoids) observed by SEM in the course of microanalyses and morphological examinations.

The limited evaluation of the microfauna was due to the facts that (1) their presence was not expected and (2) the techniques adopted for dust analyses were not specific for observing infestation by animalcula. Moreover, the extraction of dusts, in which the presence of animalcula was detected, was made after the public exhibition of the Shroud in Turin's cathedral where, under the care of Turin's Polytechnic, the Shroud was placed in isolation from the surrounding atmosphere by means of inert gas (nitrogen) for 40 days.

As a result, the sampling of dusts and unexpected microfauna was made in the best conditions for inert materials but not for living micro-organisms. It was therefore, not possible to establish in subsequent analyses whether the microfauna found in the dusts (and therefore on the cloth) were alive before, during, or immediately after the exhibition of the Shroud. However, sufficient time has probably elapsed for reimplantation of new living colonies, whose identification should provide precise information on the current conditions of the cloth and important clues for suitable techniques for cloth treatment and preservation. Hence, it is

ecessary for proper conservation evaluation to establish the biological nvironment on the Shroud.

II. METHODS AND MATERIALS

The first objective consists of a direct examination of the cloth to etect, by using optical enlargements, animalcula of the type observed in he 1978 dusts (0, 1.0, 3 mm). It is proposed to examine the cloth with a 00X stereomicroscope, linkable to a photographic apparatus for relevant ocumentation. With regard to the second objective that consists of drawing small amount of dusts from the interspace between Shroud and supporting loth, it is proposed that extraction be made using the 1978 technique over wo widely separated areas [1]. The most attractive areas for these tests ould be the back of the hands and feet which could be examined by ntroducing the instruments through the same openings already made in 1978, ow free from the impediments encountered at the time. The reopening of the lits for instrument introduction would also prove useful in allowing the erformance of different tests by other research groups (e.g., to make ualitative and quantitative microanalyses of chemical elements existing nly on the Shroud and not on the supporting cloth [2-4] and determination f image penetration depth [5]). The dusts will be analyzed using a variety f techniques such as SEM and associated x-ray fluoresence analysis.

To carry out the proposed program, the material of the Shroud will be aid on the 1978 testing frame in a horizontal position and lit by a very trong, controlled light. During all of the first stage, the table must emain horizontal, with free access from all sides. For the second stage of he work (i.e., during direct observation using a stereoscopic microscope), he table will be placed in a vertical position. Finally, these studies ill be coordinated with the microbiological examinations of Cairney [6,7].

V. EQUIPMENT

1. Sterile microsurgical instruments to make the slits for separating the Shroud and backing cloth (in several places)
2. Aspirator with sterile hoses and sterile suction fittings
3. Sterile filters for dust collection and sterile containers for macrospecimens
4. Instrument bench (portable)
5. 1 bench-type stereoscopic microscope with interchangeable lenses
6. 1 Zeiss Zoom stereoscopic microscope with floor mounting
7. 1 portable Peak microscope for dust (100x)
8. 2 cameras for microscope
9. 1 Polaroid camera for microscope
10. Electronic and Optical control instruments
11. 3 documentation photographic equipment
12. Films, filters, supports, flashbulbs for photography
13. Miscellaneous

. TIME REQUIRED

A. Pre-Shroud in Turin: 4 hours
B. On-Shroud in Turin:

1.	Reopening of slits and drawing of dusts	3 hours
2.	Microscopic examination of the cloth	6 hours
C.	Post-Shroud in Turin:	4 hours
D.	At home:	1000 hours

VI. REFERENCES

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5. Penetration Depth Measurement of the Body Image into the Shroud - Jackson, Ph.D.; Gilbert, Ph.D.; Miller, (Work Package) 1984 STURP Proposal.
6. Microbiological Analysis of Iron Oxide Deposits on the Shroud of Turin - Cairney, Ph.D., (Work Package) 1984 STURP Proposal.
7. Microbiological Analysis for On-Site Conservation Studies of the Turin Shroud - Cairney, Ph.D., (Work Package) 1984 STURP Proposal.

PARTICLE ANALYSIS FROM THE FOOT REGION AND BOTTOM OF THE SHROUD

PRINCIPAL INVESTIGATOR: J. H. Heller, M.D.
New England Institute

I. OBJECTIVE

To determine the geographical origin of particulate debris residing on the dorsal foot image and bottom of the Shroud.

II. STATEMENT OF THE PROBLEM

A. Introduction

There are two sources of material on the Shroud that have never been tested or evaluated. One is "dirt" on the foot of the man in the Shroud. The second is "dirt" along the bottom margin of the Shroud. The "dirt" on the foot was examined microscopically by the STURP group in 1978 [1]. It appeared to be soil, but this must remain a tentative conclusion since the microscopic facility at the time was low power (100X). However, if this is correct, it may be possible to obtain very significant data as to where the soil originated. To do this, one must have very sensitive instrumentation, since the expected sample size is extremely small. In addition to a complete analysis of the particles, we shall need isotope ratios. Such information will be needed if we hope to be able to cross index the information obtained with the extensive samplings of surface material already measured and catalogued by geochemists around the world. The amount of material for analysis is sparse and will probably be in the microgram to milligram range.

The analytic technique proposed is Laser Volitilization and Ionization which employ specialized equipment. Laser Desorption Mass Spectroscopy (LDMS) systems use many different lasers from the IR to the UV with delivery from picoseconds (pulsed) to Continuous Wave (CW). Usually, LDMS systems use a Time of Flight Mass Spectrometer (TOFMS). For successful time of flight mass analysis, pulses must have a power density of 10^6 - 10^{10} W/cm^2 to produce an adequate number of ions which are detected by the mass spectrometer. Of the various types of systems which exist, the two which appear to have the best applicability are produced by Leybold-Heraeus, the Lamma 500 and the Lamma 1000.

The 500 is designed for thin films or microparticles in a transmission mode while the 1000 works on incident laser irradiation. The 1000 is to the 500 what SEM (Scanning Electron Microscope) is to TEM (Transmission Electron Microscope). Both the 500 and 1000 use the same lasers, TOF, electronics and optics. Although other techniques have their advantages, the Lammas appear to be the instruments of choice.

B. Samples

On the Shroud, there are two classes of dirt as discussed above: (1) the material on the foot (which is probably soil) and (2) the material on the bottom of the cloth, whose nature is unknown. The latter material, in all probability, is a mixture of substances, and it must be assumed that

inorganic as well as organic materials are present. One must further assume that the material is particulate as well as non-particulate. Non-particulate organics and inorganics may be absorbed by or adsorbed to the linen fibers. Micro-elution schemes involving aqueous solvents, acidic or basic, and a series of organic solvents, methanol, ethanol, benzene, toluene, acetone, carbon tetrachloride, chloroform, pyridine, ethyl acetate, dimethyl formamide, cyclohexane, ether, morpholine and dioxane, among others, will be used to extract non-particulate matter. This will be undertaken in situ by Drs. Alan Adler and Rod McNeil [2]. The particulate matter on the foot, as well as the lower edge of the Shroud, will be sampled by micromanipulator by Dr. McNeil [2].

C. Analysis

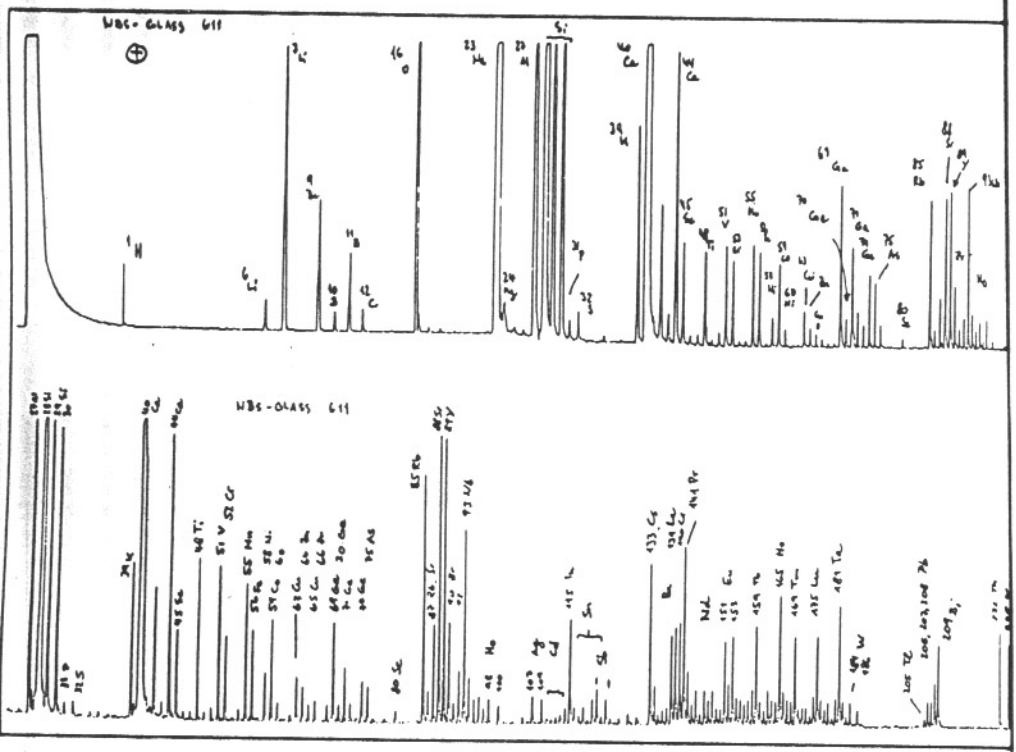
It is highly probable that non-particulate matter can also coat particles. It will therefore be necessary to sample the surface of these particles. This will require a device which will permit sampling of the entire surface so as to proceed in analyzing the particle in layers since it may be composite in nature.

In addition, particles and microfibers must be observable microscopically - in various modes, including phase contrast so that various loci on the surface can be sampled. Further, the analytical instrument must be capable of obtaining a complete elemental analysis including isotopic species. However, a further requirement is the ability of evaluating organic and biologic molecules which will probably be on the surface of microfibers and particles or deeper within them, since some or many of the particles may consist of amorphous material which should be sampled layer by layer. For all these functions, instruments of great versatility are required. The Lammas 500 and 1000 appear to be optimal for this purpose as can be seen below.

The Lamma machines, in addition to complete elemental analysis from H to U, can determine isotope ratios and can identify many organic and biologic molecular species. The 500 has two lasers - a low powered (2mW) visible wavelength (613 nm) He-Ne search laser that can be focused to a spot of 0.5 microns diameter. Colinear with it is a Q-switched (pulse width 15 ns) neodymium-YAG laser whose output is wavelength quadrupled to provide high power density (10^{10} - 10^{11} Wcm^{-2}). This power is continuously variable, which is essential for the versatility of the instrument. Visualization of the sample and the He-Ne laser spot is accomplished by a Leitz binocular microscope with Zeiss objectives permitting 100 to 1250 magnification. In the 500, one can use transmission, reflection, phase contrast, while in the 1000 the light is in the reflective mode and the optical magnification is less (i.e. oil immersion is infeasible).

As an example of the detection capabilities of the Lamma 1000, consider an analysis of a doped glass sample in which 60 elements were added in amounts of about 500 ppm to the glass matrix which was 72% SiO_2, 12% CaO, 14% Na_2O, 2% Al_2O_3. This is NBS sample #611. Figure 1 is the positive spectra of this glass. (See Figure 1.)

FIGURE 1.



L A M M A 5 0 0

DETECTION LIMITS

Element	Absolute (g)	Relative (ppmw)
Li	2×10^{-20}	0.2
B	1×10^{-20}	0.1
Na	2×10^{-20}	0.2
Mg	4×10^{-20}	0.4
Al	2×10^{-20}	0.2
K	1×10^{-20}	0.2
Ca	1×10^{-19}	1.0
Cu	2×10^{-18}	20.0
Rb	5×10^{-20}	0.5
Cs	3×10^{-20}	0.3
Sr	5×10^{-20}	0.5
Ag	1×10^{-19}	1.0
Ba	5×10^{-19}	0.5
Rb	1×10^{-19}	0.3
W	2×10^{-19}	2.0

Sample volume: 3×10^{-13} g

TABLE 1

In addition, detection limits of some elements can be seen in Table 1. Dutch researchers have used Lamma for the analysis of soil samples [3]. They point out that where the particles are small, the Lamma is preferred over electron microprobe. Speed, accuracy, and analysis of amorphous material are among the reasons for preference. In another evaluation [4], a comparison is made of Electron Surface Chemical Analysis (ESCA) and Secondary Ion Mass Spectrometry (SIMS) with Lamma 500, and the latter is preferred when the number of atoms are very few - i.e. Fluorine in a single prism of tooth enamel. This example illustrates how subtle contamination by adventitious atoms (or molecules) can contribute significantly to the understanding of the characteristics of the material being analyzed.

The capacity of TOFMS to identify molecular material (on or in particles and fibrils) is illustrated as follows. Considerable ability to evaluate organic and biological material is reflected in the literature. These include:

Polycyclic aromatics [5]
Benzalkonium chlorides [6]
Zwitterionic quaternary amonium salts [7]
Vegetative bacterial cells [8]
Bile acides [9]
Diesel exhaust particles [10]
Polymers [11]
Heart and sketetal muscle [12]
Polyfluoroethylenes [13]
Organo-metallics [14]
Carbonaceous particulates [15]
Amino acids [16]

III. METHODS AND MATERIALS

After samples are collected by McNeil and Adler [2], I have the promise of two weeks access to the 500 and the 1000. Leybold-Heraeus has made the two instruments available to me in their applications lab in Cologne, Germany for two weeks. This, of course, will necessitate going to Germany for this period. Since no instrument is a universal analyzer, I may have to fall back on more conventional instrumentation, should the necessity arise. Fortunately, this type of instrumentation is also available in the same laboratory. These include photoelectron spectroscopy (XPS), Auger emmision spectroscopy (AES), ion scattering spectroscopy (ISS), and secondary ion mass spectroscopy (SIMS). In these studies, I will use controls and compare results from appropriate geographical soil sample data (the controls will be linen fibers which have been doped with one to five organic materials plus known soil particles which have had organic material attached to the surface).

IV. EQUIPMENT

Sampling micromanipulator [2].

V. TIME REQUIRED

1.	Pre-Shroud in Turin	2 hours
2.	On Shroud in Turin	5 hours
3.	Post-Shroud in Turin	2 hours
4.	At home	500 hours

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PENETRATION DEPTH MEASUREMENT OF BODY IMAGE INTO THE SHROUD

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I. OBJECTIVE

To determine the penetration depth of the visible body image into the Shroud cloth.

II. STATEMENT OF THE PROBLEM

The 1969/1973 Scientific Commission first reported that the body image resides only on the surface fibrils of the threads comprising the weave of the cloth [1]. This same conclusion was later reported by Pellicori [2] via microscopic evaluation and Jackson [3] from transmission photographs taken by Schwortz. However, these studies have all been qualitative and a quantitative determination of the depth of body image discoloration has yet to be made.

The depth of image penetration is a very important parameter of the image to characterize because it relates to the manner in which the image formation mechanism interacted physically with the Shroud to produce color. For example, it sets limits on (1) the time in which a thermal process (e.g., from a hot statue or bas relief) could have acted [3], (2) the cloth attenuation coefficient if the image was produced by a radiative mechanism, or (3) the quantity and cloth absorptivity of the chemical substance if the image was produced chemically. It is therefore proposed that the penetration depth of the body image be determined by two techniques: (1) measurement of optical attenuation and (2) direct inspection under a binocular microscope. Both methods are nondestructive unlike an alternate approach in which a body image thread might be removed and viewed microscopically from the side. Such a thread removal might leave an undesirable scar in the body image.

III. METHODS AND MATERIALS

In 1978 the Shroud was observed and photographed by reflected and transmitted light. The resulting photography showed that in reflected light the body image was as intense as certain perimeter regions of the 1532 fire damage, but in transmitted light the body image was considerably less intense (but visible) than the same fire damage regions [3]. Since the fire damages penetrate the entire thickness of the Shroud (note symmetry of burn

marks indicating cloth penetration when Shroud was folded at the 1532 fire) and therefore attenuate light more than the body image which resides only on the surface, it should be possible to measure the relative degree of attenuation and calculate the depth of image color penetration. A similar procedure has also been suggested by Schwalbe [4] to eliminate some of the visual perturbation of the Shroud image due to the 1532 fire.

The procedure to be used is as follows. First, with the Shroud held in a vertical configuration, body image and scorch regions on the Shroud of identical reflectivity will be tentatively identified via existing 1978 photographs. Reflectance spectra of these regions will then be measured directly on the Shroud with the same scanning reflectometer to be used in another work package [5]. Slight positional adjustments will be made as necessary so as to make corresponding body image and reflectance spectra identical to within the precision of the reflectometer (which will be characterized). These equivalent reflectance regions will then be examined and photographed microscopically so as to ensure the absence of significant surface contamination which might cause unwanted attenuation. The reflectometer source will then be positioned at the rear of the Shroud and the transmitted light flux, I, measured at all wavelengths within the spectral range of the reflectometer. It is desirable that the backing cloth be removed, but if this cannot be done, the incident light can be channeled to the rear surface of the Shroud with a light pipe/prism device inserted through a small opening between the Shroud and backing cloth. The image thickness, t, will then be calculated via the formula

$$\left(\frac{I_i}{I_c}\right) = \left(\frac{I_b}{I_c}\right)^{t/T} \qquad (1)$$

where I_i = transmitted flux in an image region

I_c = transmitted flux in a pure cloth region

I_b = transmitted flux in a burn region of equal reflectivity as the image region

T = average thickness of the Shroud.

Equation (1), derived in the Appendix at the end of this work package, is valid for all wavelengths and assumes that each body and burn region pairs are designated so as to have identical reflectivities (so that the average attenuation of the colored layers of these regions can be assumed to be equal).

In actual practice, a more complex form of Equation (1) will be used to account for second order effects such as (1) light passing through interfibril spaces, (2) inhomogeneity of the cloth structure (which can be evaluated by X-radiographs), (3) cylindrical nature of threads, and (4) reflectivity variations at the back surface of the cloth.

This technique has been applied to existing transmitted light photographs [6] by the Principal Investigator where the intensities in Equation (1) have been replaced by photographic transmittance (with the effect of the film-γ taken into account.) In these photographs, the faint shroud image was visible and sampling locations included probable cloth/body contact and non-contact locations. All second-order effects described above were estimated and corrected for. The resulting value for t/T was 13.7±12.0% or t =36.8±32.2 microns (using T = 269 microns - average Shroud thickness). This value is approximately that estimated visually (50 microns) [7] and, therefore, appears to demonstrate the feasibility of the proposed technique. Further feasibility calculations are found in the Appendix. Finally, all thruput intensities will be photographed by electronic means [8] so as to allow microdensitometric evaluation, if necessary later, of image penetration as discussed above.

B. Direct Examination

A second method for determing the depth of image penetration is to examine the body image threads at approximately 100X magnification using a stereomicroscope. Illumination will be adjusted so as to minimize spectral reflections which in 1978 made it difficult to distinguish between colored and noncolored fibrils. Needle and forceps will be used to probe the colored fibrils so as to determine the average number of colored fibril layers in the body image. Knowing the average fibril thickness, the image depth will be calculated. All regions examined will be photographed and documented.

C. Discussion

Both methods have advantages and disadvantages in measuring the depth of image penetration. The optical transmission approach is easy to use, completely objective, and can sample many image locations, thereby providing a significant statistical base from which the determination of image penetration can be made. Further, if the statistical uncertainties turn out to be sufficiently small, then it might be possible to see if a correlation exists between image intensity and penetration depth. If, however, it turns out that the body image is comprised of just one monolayer of colored fibrils with shading resulting from a varying ratio of colored to uncolored fibrils in this layer, then this would show up as an average image depth less than one fibril deep and a correlation between image intensity and "average image thickness" should exist. Such a result, if measurement errors are sufficiently small, should provide an in situ measure of the colored to uncolored fibril ratio which could be compared with measurements of this ratio via micro-image analysis of another work package [8]. The disadvantage of the optical technique is that, unless part of the backing cloth can be removed, the transmission measurements must be made through it. However, perturbing effects of the backing cloth, if significant, can probably be compensated for by measuring the reflectance spectrum of the backing cloth at each probe point. In addition, since multispectral transmission data is being recorded, perturbation effects (including those due to particulation contamination) should be easily recognizable from the body image attenuation.

The advantage of the probe method is that it involves direct inspection f fibril discoloration. The disadvantage is that, unlike the optical ethod, it involves the subjective judgment as to whether or not a given ibril is colored; this may be somewhat difficult due to the faintness of he image and the specular component of the reflected illumination as iscussed above.

V. EQUIPMENT

1. Reflectometer with detachable photodetector (supplied by Oriel Corporation)
2. 1978 Test Frame with removable back panels
3. Stereo-microscope with and tripod and camera for photo-documentation.
4. Vibration-free stand for entire experiment.

V. TIME REQUIRED

1.	Pre-Shroud in Turin	10 hours
2.	On Shroud in Turin	
	A. Optical Attenuation	12 hours
	B. Direct Examination	6 hours
3.	Post-Shroud in Turin	4 hours
4.	At Home	200 hours

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APPENDIX

To derive Equation (1), consider a beam of intensity I_o impinging upon the back surface of the Shroud. Assume that the total cloth thickness is T and that the penetration depth of the body image is t. Let K_i, K_b, K_c and r_i, r_b, r_c represent the attenuation and back surface reflectivity coefficients of the image, burn, and cloth fibril regions respectively. The thruput radiation flux at the front surface for each region and wavelength is then

$$I_c = (1-r_c)I_o e^{-K_c T} \quad \text{(pure cloth)} \tag{2}$$

$$I_b = (1-r_b)I_o e^{-K_b T} \quad \text{(1532 scorch)} \tag{3}$$

$$I_i = (1-r_i)I_o e^{-K_i t - K_c (T-t)} \quad \text{(image)} \tag{4}$$

Let us further assume that the scorch region is chosen so that the front surface reflectivity is the same as the given image region. Assuming this implies that the fiber discolorations in both regions are the same (on the average), we require,

$$K_i = K_b \tag{5}$$

Further, since the Shroud image does not penetrate the cloth to the back side, the back surface reflectivities of the cloth and image regions are equal; that is

$$r_c = r_i \tag{6}$$

Thus,

$$\frac{I_i}{I_c} = e^{-(K_i - K_c)t} \tag{7}$$

and

$$\frac{(1-r_c)}{(1-r_b)} \frac{I_b}{I_c} = e^{-(K_i - K_c)T} \tag{8}$$

Hence,

$$\frac{I_i}{I_c} = \left[\left(\frac{1-r_c}{1-r_b} \right) \frac{I_b}{I_c} \right]^{t/T} \tag{9}$$

relation independent of K_i, K_b, and K_c. Since the burn discolorations penetrate through the cloth, r_b is approximately the same as the front surface reflectivity of the burn which was chosen to be that of the image front surface reflectivity. Reflectance measurements in 1978 indicate that $r_c \simeq .35$ and $r_b \simeq r_i \simeq .29$. Hence,

$$\frac{1-r_c}{1-r_b} \simeq .92 \tag{10}$$

Thus, to first order (since t/T is small), Equation (9) is equivalent to Equation (1).

In actuality, the Shroud cloth is not a uniform medium but has openings in its weave structure through which a small fraction, X, of the incident flux, I_o, can pass. If Equations (2-4) are modified to account for this effect, Equation (1) takes on the form

$$\left[\left(\frac{I_i}{I_c}\right) d - X\right] = \left[(1-X)(e^{-K_c T})\right]^{1-t/T} \left[\left(\frac{I_b}{I_c}\right) d - X\right]^{t/T} \tag{9}$$

where $d = X+(1-X)e^{-K_c T}$. It can be shown if $X \ll e^{-K_c T}$ (i.e., the flux change due to interthread spaces is small compared to the change due to attenuation), Equation (9) becomes (1). From microscopic photographs of the Shroud, X appears to be about 2%. Microdensitometer readings through laboratory linen threads indicate the $e^{-K_c T} \approx 10\%$. Thus, Equation (1) appears to be a satisfactory approximation, although in actual data reduction, Equation (9) would be used.

We can estimate the instrument sensitivity required to detect a penetration depth t from Equation (1). We first note that the intensity ratio, I_b/I_c, is related to the ratio of the transmittances, T_b/T_c, of the 1978 transmitted light photographs [6] by

$$\frac{I_b}{I_c} = \left(\frac{T_b}{T_c}\right)^{-1/\gamma} \tag{10}$$

where γ is the slope of the Density/logE curve of the film used. Microdensitometric measurements of the photographs indicate that for $T_b/T_c \approx .34$ and $\gamma = -1.7$ [9], $I_b/I_c \approx .53$. Hence, according to Equation (1) we must be able to measure the ratio I_i/I_c to within

$$I_i/I_c \approx (.53)^{t/T} \qquad (11)$$

If, as a worst case, the Shroud image resides only on the surface fibrils, roughly 15 microns thick [7], then the ratio $t/T \approx 15/269$ (where T is taken to be the average Shroud thickness of 269 microns). Since this represents the greatest sensitivity required, we must therefore be prepared to measure I_i/I_c to roughly $(.53)^{15/269} = 97\%$ accuracy. This is approximately the detection limit of the Gilbert's 1978 reflectometer [10]. The estimated 97% sensitivity, however, probably applies only to long (red) wavelengths since in the transmission photography (from which the above transmission measurements were used) the Shroud appears orange to red. The chromophore causing the image is known to absorb shorter (blue) wavelengths more readily and hence the difference between K_i and K_c should be greater at short wavelengths. According to Equation (7) the expected ratio I_i/I_c should therefore be less (implying lower required detection sensitivity) for a given image thickness t. Hence, the proposed image thickness measurement appears feasible, particularly at short wavelengths (in Turin, the sensitivity level of the experiment will be determined using a clean cloth region to represent an image region of zero thickness).

PHOTOGRAPHIC AND IMAGE-ANALYSIS STUDY

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I. OBJECTIVE

We propose to supplement existing photographic documentation on the Shroud of Turin. This work will provide indexed views at various locations in both reflection and transmission modes of illumination. Selected photographs will be digitized for subsequent computer analysis. We shall apply the new information to research on the possible connection of the Shroud image to Byzantine iconography and to the question of Filas' proposed coin images. In addition, the blood areas will be photographed with back-lit illumination. These data should aid in further study of the bloodstain morphology.

II. STATEMENT OF THE PROBLEM

A. Byzantine Iconography.

Wilson [1] considered the possible influence of the Shroud image on Byzantine artistic tradition. These studies have been continued more recently by Yarborough [2] and Whanger [3]. The approach adopted by these investigators is to identify features common to both the facial portion of the Shroud image and renditions of Christ on icons and coins. To facilitate visual comparisons, Whanger [3] describes his "polarized image overlay technique" which allows a continuous visual transition from one image to another. With this technique he locates at least 145 "points of congruence" between the Shroud and the engraved facial image on a Byzantine coin of Justinian II, which was struck between AD 692 and 695. Similar comparisons with an encaustic icon from the period AD 527 to 565 show 170 points. Present theories have the Shroud serving as a stylistic model as early as the 6th century.

There are problems with such comparisons. A major difficulty derives from the background motteling of the cloth [4] and the interference or "noise" it produces in the image. The fire damage and the effects of aging have produced changes in the fabric that are chemically similar to the image [5]. We fear that much of this degradation is likely to have occurred after the 6th or 7th centuries. Correlations involving later features are clearly spurious. The problem is that without some way of knowing how the image

appeared in the early middle ages, comparative studies are subject to a preponderance of false congruences. The reliability of such work is questionable as long as possible effects of the fire damage and age discoloration have not been eliminated in some systematic way.

The heterogeneous nature of the damage precludes any global correction. For the fire and water stains this problem is quite evident. For aging, the extent of the deterioration is sensitively dependent on the bulk and surface characteristics of each thread lot used in the weave. However, it should be remembered that fire, water, and aging discolorations are all largely bulk phenomena; whereas, the image is a surface effect (recall that visible light transmission photographs clearly show the fire and water damage, but the image is only faintly visible). The mottled discolorations in these photos are due in part to differential effects of aging and the nonuniform density of the cloth.

The facial area of the image is of particular interest. Here, the low-energy radiographs [6] show the cloth density to be reasonably homogeneous. We propose to digitize both transmission and reflection photographs in this area, perhaps in each of three wavelength (color) intervals. The intensity of each transmission photograph will then be adjusted to match that in the corresponding background or fire-damaged areas of the reflection photographs. An algebraic difference can then be taken between the two sets of pixel values. The final result should approximate the original condition of the image as well as it is possible to do.

It is interesting to consider the possible influences of the Shroud on Byzantine art. The enumeration of "points of congruences" is a reasonable approach to this problem. But, we think the work should proceed with representations of the image for which some attempt has been made to eliminate the motteling effects of more recent origin.

B. Filas Coins Inscription Hypothesis Examination

The work of Fr. Filas has been publicized broadly and is by now well known [7]. Observations of photographic enlargements of the right-eye regions of the 1933 Enrie photographs reveal lituus- and letter-like features. These, Filas claims, represent the image transfer from a lepton coin. He contends this finding is sufficient to date the Shroud to ca. 30 AD. The coin issue has at times generated heated controversy. Most members of the technical community have been unwilling to accept the interpretation and conclusions Filas has offered. The difficulty is not so much in recognizing the features he points out as with the uncertainty about what these features actually represent. Enrie's photographs record not only the image patterns but also the cloth weave. Reflections from the weave generate a significant but unknown contribution of light and shadow patterns that possess approximately the same spatial frequencies as the alleged letter images.

In retrospect, we view the reaction to Filas' work as quite predictible. It is nearly universal scientific practice to ignore any claimed effect for which the signal-to-noise ratio approximates unity. And, yet, however suspect his evidence may seem, the fact remains that Filas has at least produced something concrete. Some feel the coin problem is not worth considering, but few could dismiss the work as insignificant if it

were in fact proven valid. As Filas suggests, the discovery would be strong circumstantial evidence for a first century origin.

But, in our estimation, the observation has potentially greater significance. By far the most scientific evidence amassed thus far pertains to the composition of the image rather than to how it arrived on the cloth. We submit that if Filas' claims are valid, the information is most important for characterizing the point spread function of the image transfer mechanism. If the images of the letters with their small internal features (ca. 0.5 mm linear dimension) were indeed preserved, the resolution of the transfer mechanism must be at least an order of magnitude greater than what has been estimated from the observed images of the lips (ca. 5 mm separation). A positive result would stand as supporting evidence for an image transfer by direct contact.

In view of the fundamental problem noted earlier, the first task must be to eliminate the weave pattern from close-up photographs of the eye regions. There have already been some attempts to do this. All involve low-pass filtering by one means or another. The earliest of these is seen in Filas' original work [7]. There he states that the lituus and letter-like features are more clearly visible in the second- to fifth-generation photographs. The effect is apparently enhanced by successive photographic reproduction; it is well known that replication diminishes image clarity. In other words, successive photographic reproduction attenuates higher spatial frequencies so that later generation copies represent low-pass-filtered versions of the original.

In general, digital image filtering can serve the same function as analog dark-room methods, but the flexibility of digital techniques is vastly greater. Recently, Haralick [8] applied contrast stretching and low-pass digital filtering to both the Enrie and Miller photographs. In his opinion, the results show at least partial success in isolating image features in the eye regions. In our view, the results are questionable.

Filtering techniques may well reveal previously obscured structures, but the problem lies in the interpretation of these structures. The difficulty is not with the analysis techniques themselves; contrast stretching and digital filtering are entirely appropriate. The problem derives from a lack of information in the original data. The only photographs taken for detailed studies of the alleged coins have been single, nonspecific monochromatic renditions. Image and weave patterns are mapped into light and dark structures of similar appearance, and their identities are lost. Image-processing techniques cannot recover this missing information, and it is doubtful that any convincing study can be made of the coin question with existing data. The weave-interference problem can be solved, but to do so will require the recovery and processing of information from two or more bands of the color spectrum.

There are at least two possible ways of doing this. Recall from the reflectance spectra of Gilbert and Gilbert [4], image density is a monotonically decreasing function of wavelength. In reflected light the image contrast is greater at shorter wavelengths than it is at longer. The weave structure, on the other hand, is nearly neutral in its reflectance behavior. (We believe this is so because of the spectral reflectance character of the background cloth areas in the photomicrographs [10].) We, therefore, propose to digitize two "perfectly" indexed photographs, one

taken through either a blue or a UV transmission filter, the other through a red filter. The density (or darkness) of one digitized photograph will then be adjusted until the weave contrast matches that of the other. A pixel-by-pixel subtraction of the red photograph from the blue (or UV) should then leave only the image.

A second possibility closely follows the procedure outlined in section "A" of this proposal. Again, we intend to photograph the eye region in both reflected and transmitted light, but for this study we will first insert a diffusing plate of frosted glass between the Shroud and the backing cloth. (The purpose of the plate is to eliminate the weave pattern of the Holland cloth in transmission). The two digitized photographs will then be scaled and subtracted in a manner similar to that described above.

The procedures outlined here pertain to photographs taken in only two color bands, but there is no fundamental reason for this restriction. Indexed photographs in three or even four bands could be taken. Each pixel would then be represented as a three- or four-dimensional vector, and standard multivariate techniques could be applied to the set. The color-separation photography proposed here is not very different from recent Landsat data where multivariate analyses have found successful application [9]. These computational techniques are quite powerful and far less subjective than the simple subtraction method outlined above. We propose to explore them extensively.

C. Transmission Photography of the Bloodstains

The bloodstain morphology bears on several interesting questions. Meacham [11] cites Rodante [12] in noting that several clots have the distinctive characteristics of either venous or arterial blood, as seen in the density, uniformity, and modality of coagulation. Ricci [13] observes a density distribution in the side-wound area that, to him, resembles a discrete injury from an edge-shaped weapon of the same shape and dimensions as the tip of a 1st-century Roman lance. Others [14] see no such resemblance. There has also been some informal discussion among STURP members about possible evidence for a double-nail imprint in the foot-wound area.

Despite the considerable photographic documentation available on the Shroud, there still lack close-up, visible transmission pictures of the bloodstain regions. We propose to photograph the stains at the wrist, feet, head, side-wound area, and back. If time permits, we may also document one or more of the scourge marks. The illumination for each will be adjusted and controlled to reveal as clearly as possible the morphology (density distribution) of the stain.

The new data will supplement the visible reflection and UV-fluorescence photographs in these areas. Together, they should constitute complete photographic documentation of the major bloodstain regions. Our results will be made available to pathologists and forensic examiners [15] to aid in their research.

III. METHODS AND MATERIALS

The above work plan has the initial photography on site in Turin and later digital analysis in the laboratory. However, our description is not meant to exclude other approaches to the problem. Thus, H. W. Johnson will

pply dark-room methods to complement the digital approach to subtracting he weave interferences. We also intend to collaborate with Jackson et al. 16] who propose to carry out similar, but independent, studies with real-ime electronic video equipment. The real-time and photographic techniques omplement one another nicely. One advantage to the real-time approach is hat results can be inspected immediately and adjustments made to the echnique as needed. The advantages to large-format film photography are he potentially significant gains in final image resolution. Our results hould also yield hardcopy that can be made available for digitization and nalysis by independent investigators.

The equipment and procedures planned for Turin are similar to those sed by Miller in 1978. All photographs in this study will be taken with an " x 10" camera with flat-field apochromatic lenses mounted on the STURP amera rail. For improved resolution, we plan to use vacuum sheet film olders and electronic flash illumination. Reticles with hold-down magnets ill be used for the critical registration of the eye regions. Color eparation will be accomplished with standard filters and with post-rocessing of the B/W photographs. Color-film processing will be done in taly between shooting sessions.

IV. EQUIPMENT

We will require the following equipment for the experiments described bove:

A. Registration reticles (glass plates, 8" x 10", 5" x 7", and 4" x 5")
B. 8" x 10" camera with flat-field apochromatic lenses (300 mm and 200 mm)
C. Vacuum sheet film holders (20)
D. Vacuum pump (2)
E. STURP camera rail
F. Poloroid, color and B/W film (including processing)
G. Electronic flash illumination equipment
H. Color separation filters (red, green, blue, and UV)
I. Beam splitter (for axial lighting)
J. Flashed opal glass plates of various sizes
K. Calibrated reflectance and transmission reference standards
L. Hold-down magnets for reticles
M. Photo exposure meters (2)
N. Misc. tools

V. TIME REQUIRED

A.	Pre-Shroud in Turin:	4 hours
B.	On-Shroud in Turin:	12 hours (2 blocks of 6)
C.	Post-Shroud in Turin:	20 hours
D.	At home:	400 hours

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RADIOGRAPHY OF THE TURIN SHROUD AT LOW ENERGIES

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I. OBJECTIVE

A. To re-radiograph the Shroud with improved techniques and equipment.
B. To produce stereoradiographs of selected areas.
C. To interpret the data collected in A and B.

II. STATEMENT OF THE PROBLEM

A. Introduction

Based on the experience gained in 1978 [1,2], a more comprehensive radiographic examination of the Shroud is proposed.

Quality of the x-radiation is denoted by a term called half-value thickness. This is determined by a measurement of x-ray attenuation through a material of known composition, for example chemically pure, cellulosic filter paper. The amount of change in density and/or thickness of a given material that is measurable determines the sensitivity of the radiographic technique. One of the factors which determines this sensitivity is the x-ray energy used to produce a film image. A radiation source whose output has a high portion of "soft" (low photon energy, long wavelength) x-rays would provide greater sensitivity to material differences than a source of "hard" (high photon energy, short wavelength) x-rays which are more penetrating. To illustrate this, we have plotted, in Figure 1, the mass absorption coefficients of two materials as a function of x-ray energy. The right most vertical dashed line rising from the ordinate represents the effective x-ray energy used in 1978. A greater quantity of "soft" x-rays has the effect of shifting the effective x-ray energy downward as represented by the left hand vertical dashed line.

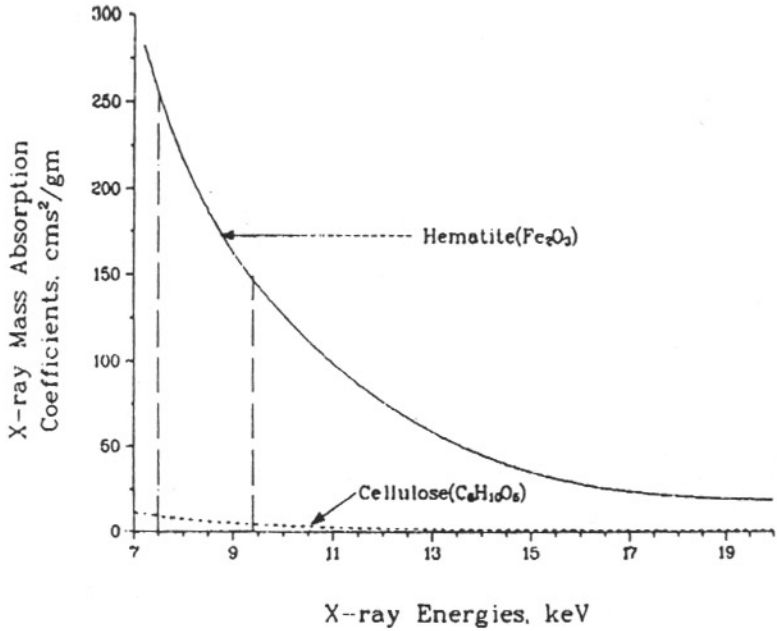


Figure 1

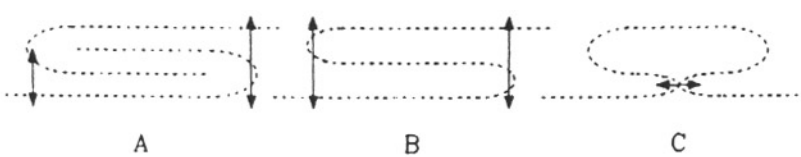


Figure 2.

The examination in 1978 was not complete because of the misplacement of an auxillary panel and because the dimensions of the Shroud were greater than those of the holding frame. The extra panel, which was more narrow than the others, would have permitted adjacent films to overlap areas of the Shroud, thus insuring redundant coverage. Edges of the Shroud and attached border cloths were not radiographed because they were obscured by the fixture frame. Relocation of the Shroud on the frame will permit us to examine these features as never before. The loss of a reference wedge in 1978 hindered precise documentation of the x-ray beam at that time.

Observed in the 1978 radiographs [1,2] are many extraneous objects, some of which appear to be particles and others which are wire-like. Other artifacts are circular and of about the same radiographic opacity as the linen and cotton. In addition, we have observed stitching around holes and patches. Furthermore, there are streaks of x-ray opaque material which may be folds or creases in the linen in which may be entrapped debris. In particular, a foldmark of considerable interest intersects the 1532 fire patch region and this foldmark has been suggested by Jackson [3,4] as a candidate for a hypothetical Mandylion fold line. A feature of great interest to many Sindonologists is what appears to be a "seam" running parallel to one long edge. Figure 2 illustrates three possibilities (labeled A, B, and C) for the formation of such a feature. Since the Shroud material on the edge side of this seam is proposed to be C-14 dated [5], it is essential to know whether this material is an integral part of the Shroud or an addition. We propose to examine the above features and others with a technique known as stereoradiography. Stereoradiographs are produced by making two exposures on separate films. The x-ray source is positioned to one side of an imaginary line for one exposure and then moved an equidistant to the other side of the imaginary line. By means of a stereoscope, the binocular vision of an observer allows the perception of depth. Thus, layers and objects between layers may be spatially resolved in a third dimension.

B. Principal Purpose

The principal purpose of our proposed experiment is to examine radiographically the Shroud in more detail than was possible in 1978. Examination of the edges of the shroud and edging will be accomplished by repositioning the cloths as necessary. Stereoradiographs will permit us to resolve in depth many extraneous materials, and to resolve layers and foldlines for Jackson's studies [4] in better detail.

C. Advantages of Transmission Radiography

1. X-rays penetrate materials and produce shadowgraphs in film emulsions, thereby allowing hidden information to become visible.

2. Internal features of an opaque subject can be spatially resolved and displayed in a three-dimensional format with stereoradiography.

3. Differential absorption due to material density, thickness, and atomic number (Z) provide a semi-quantitative identification of materials. For example, the wire-like objects observed in the 1978 radiographs [1,2] are assumed to be wire because of their dimensions and opacity compared to linen and cotton. Also certain circular features are

presumed to be a low Z material because of their relative transparency (or opacity). Similar statements can be made concerning the apparent absence of high Z inorganic pigment comprising the body image.

4. The dimensions of objects or holes can be measured with reasonable precision. Patches cover holes created in the 1532 fire. The dimensions and shape of these holes would permit a more exacting determination of the manner in which the Shroud was folded at the time.

5. The test is nondestructive and will cause no harm to the cloth, image, or other features.

6. Radiographs, when carefully processed and preserved, are considered permanent records. They can be easily copied and such copies could be provided to any researcher at a reasonable cost if proper arrangements can be made and facilities are available.

D. Disadvantages of Transmission Radiography

1. Requires expensive, electrically powered equipment.

2. X-rays can be harmful to people (not the Shroud) and deleterious to other experiments. Low energy x-rays are relatively easily attenuated and proper safeguards are easily implemented (as in 1978) to prevent direct exposure to the main beam. Other experiments, such as photography, which might be affected would be scheduled at other times.

III. METHODS AND MATERIALS

The x-ray source that we propose to use will produce a greater quantity of long wavelength ("softer") radiation than the one used in 1978. This is desirable, as discussed above and illustrated in Figure 1, because it will improve sensitivity to material differences. The x-ray tube will have a beryllium (Be) window of 0.25 mm or less while the previous tube had a 1 mm. thick Be window. In addition, we will select an x-ray target material between a Z of 24 (chromium) and 29 (copper) to enhance the radiation spectra near 7.5 keV.

The power source (generator) will be full-wave rectified and filtered to provide constant potential to the x-ray tube. The generator will also be capable of providing significantly more power than the one used in 1978. This will in turn reduce the exposure times.

To reduce x-ray attenuation by air and moisture, a helium column will be used between the x-ray source and Shroud. One end will be sealed to the x-ray tube and the other by a thin plastic film, such as Mylar or Saran. A positive internal pressure slightly above atmospheric will be maintained. This modest pressure will aid in pressing the Shroud cloths against the film packs, thereby reducing the object-to-film distance. The helium column may be made of any of several lightweight materials, cardboard or aluminum, for example. Not only will it aid in maintaining proper x-ray source alignment and distance, but it will help in safequarding people against radiation hazard.

A fixture will be designed to hold the x-ray tube. The holding fixture will have three degrees of motions to allow easy and precise positioning of the source.

The STURP 1978 frame will be used to support the Shroud as before.

Exposed films will be delivered directly to a darkroom and processed. A preliminary review will be made of each film as soon as practicable. If

this review reveals that a systems adjustment is necessary, this information will be transmitted to the radiographer, as soon as possible.

This time we propose to use a different combination of films in the film pack. One film will be a single emulsion film, seated in the film pack with the emulsion outward. The second film will be a two-emulsion film; the emulsions being the same as used on the single emulsion film. In use, the films will be mounted so that the single-emulsion is nearest the x-ray source. Due to the attenuation of the x-radiation by the single-emulsion film, the optical density of the second film may be different than the first. This is not a disadvantage; often times it is helpful, during film interpretation, to have different film densities for comparison. In addition the dynamic range of densities in the two-emulsion film will be greater than those in the single emulsion film.

If we assume that the Shroud will be mounted on the frame and that the same coordinate system is used as in 1978, we will commence with the x-ray source aligned with the junction of coordinates A1,2, and B1,2. After the first exposure, the source will be moved vertically in increments for the next two exposures. The source will then be moved to the right 20 centimeters and three exposures made in three vertical increments downward. This up and down and moving right sequence will be repeated for the full length of the Shroud.

After each six exposures, an exposure will be made in which a reference wedge constructed of chemically pure filter paper will be imaged on film. Primarily, this is to monitor the x-ray process including film processing. The reference wedge image will also aid in making quantitative densitometric measurements at home.

Next, we will make a minimum of four pair of stereoradiographs at difference locations along the "seam". Then stereo paris will be made of some creases [4]. For example, in column 9 (see Master Reference Mosaic prepared by Vern Miller) there are several creases which either cross the "seam" or a scorch mark. Request from other investigators will be honored if time and film supplies permit.

As soon as practicable after our return from Turin, copies of all films will be made and provided to Associated Investigators. Contact enhanced copies will also be provided as necessary.

Although not absolutely necessary, it would be advantageous if the Holland backing cloth could be removed from the Shroud and attached after the x-radiographic examination. This would remove the perturbing effects of the backing cloth from the radiographs. However, the decision to remove must consider the effect on the integrity of the Shroud.

Each Investigator will use whatever resources are available to interpret the radiographs. After some reasonable time, the Investigators will meet and compile results.

A data base will be established and will incorporate the coordinate system used in 1978 unless revised by STURP. Based on the first compilation, a classification system will be devised so that systematic tabulation of Shroud features may be made.

More details concerning radiography can be found in References 6-8.

IV. EQUIPMENT

(In Turin)

Radiographic and safety equipment

- 1 - Constant potential power supply, 5-50 kV
- 1 - Special x-ray tube
- 2 - Radiation survey meters
- 12 - Dosimeter with one charger
- 12 - Film badges
- 2 - Flashing beacons or lighted warning signs
- 4 - Radiation warning signs
- 22 - sets, film markers, letters A thru F
- 10 - sets, Film markers, numberals 0 thru 9
- 1 - X-ray tube positioner
- 100 - Special film packets, 14" x 17"
- 50 - Special film packets, 5" x 7"
- 6 - Helium bottles, laboratory size
- 2 - Helium reducers and regulators
- 1 - 1978 Shroud mounting table (frame)

Darkroom equipment and supplies

- 1 - Portable Darkroom
- 2 - Tanks, processing
- 3 - Inserts for tanks, 5 gal. capacity
- 3 - Tank solution agitators
- 1 - Tank heater, thermostatic
- 2 - Heavy duty dryers
- 3 - Adjustable safelights
- 6 - Safelight filters
- 2 - Thermometer
- 2 - Darkroom timers
- 3 - Darkroom aprons
- 36 - Film hangers (14" x 17")
- 12 - film hangers (5" x 7")
- 1 - Densitometer

Film inspection, interpretation and filing

- 2 - X-ray film illuminators, variable intensity with 4 sets of spare lamps for each
- 1 - Stero viewer
- 4 - Magnifiers with graticles
- 100 - Envelopes, x-ray film filing (14" x 17")
- 50 - Envelopes, x-ray film filing (8" x 10")

Miscellaneous

- 1 - Tool kit with various tool kits, hose clamps. Hoses and tubing of various lengths

(At Home)

- Contact printer
- Duplicating film
- Film processing chemicals
- X-ray film illuminators
- Magnifiers fitted with graticles
- VP-8 Image Analyzer or other image processing equipment as required by Investigators

TIME REQUIRED

A. At Turin

1. Set up - at least two days
2. Equipment checks and practice runs - 1 day
3. Test at Shroud - eighteen hours minimum in three blocks of six hours each
   a. Block 1 - complete examination of Shroud
   b. Block 2 - steroradiography of pre-selected areas
   c. Block 3 - radiography of four edges and border cloths - requires repositioning Shroud four times on frame (which may require more than six hours).

B. At home - at least 1,000 man hours by Investigators and assistants.

he time estimated does not include preparation.

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I. OBJECTIVE

To obtain more complete photographic data over a wider range of magnifications, wavelengths, angles and film format than was obtained in 1978. Improvements in equipment, techniques, and film processing will be incorporated in:

A. Color Photomicroscopy: Recorded at 3-50X on both large format and 35mm film, including stereo, of critical areas of body image and blood for further study.

B. Fluorescence photography: At 1:8 and large scale, document locations and colors of emitting or absorbing features with greater fidelity and coverage than in 1978.

C. Reflected UV photography: On octal sections, exaggerate the visually faint body image density and hence the contrast with background density.

II. STATEMENT OF THE PROBLEM

A. The photomicrographs taken in 1978 [1] contained much valuable information on body image, blood stains, scorches, and non-image areas, but suffered in the extent of coverage that they provided. For example, no skin wounds were photographed at high magnification, several important blood stains were excluded, and the sampling of body-only image areas was small. Better spatial and color fidelity will assist in answering such questions as:

- Is there blood in the skin wounds?
- What does the "serum"/blood interface look like?
- Where are particles (dirt) found?
- Can particulate material be seen in the water front zones?
- Can more detail in the skin wounds, eyes, etc. be observed?
- Can greater detail in the body-only image be observed?

- o Can blood density variations, serum, and water front zones be documented?
- o What do body, scorch, cloth, blood, waterstain fibrils look like at high magnification?

B. Fluorescence photography [2] revealed that the body-only image in contrast to some scorches does not fluoresce when excited with UV. Further, the skin wounds showed high absorption and millimeter scale sharpness in the fluorescence photos. Because the color fidelity of the emitted colors was in question, it is important to repeat this experiment to provide better data. Also, more areas need to be covered, in particular the relative fluorescense of scorches and body image. This data pertains to testing the hypothesis that the body image was the result of a thermally induced discoloration, like a cloth placed over a hot statue or bas relief.

Some questions that will be addressed are:

- o What are the fluorescent characteristics of various areas on the Shroud (e.g. body, blood, waterstain, cloth, scorch, etc.)
- o How does the "serum"/blood transition zone fluoresce?
- o Can differences between scorch and body image be recorded for later quantification and comparison with photoelectric spectrometry?
- o Do water front zones show different fluorescence?
- o What is the fluorescent pattern of the cloth weave?

C. The 1978 UV reflected photography [3] was difficult to interpret because of focus problems. We know from photoelectric spectrophotometry, UV fluorescence photography, and laboratory simulations of carbonyl compound generation in cellulose that optical absorption coefficient increases with decreasing wavelength. The search for faint images, which are invisible in white light, is thus made possible. This is pertinent to the questions of image distortion due to cloth drape and form fitting.

III. METHODS AND MATERIALS

A. Magnifications of 3-50X on both large (4"x5") format and 35mm film will be used. This will allow enlargements for image details to be studied. The illumination angle will be varied and stereo views will be made.

B. Using filtered zenon lamps, the areas of interest will be illuminated with UV wavelengths shorter than 400nm. The lens will be filtered to pass only wavelengths above 400nm, thus recording only emitted colors and not reflected UV. The scale will be 1:8 and larger.

C. With a filter passing UV while blocking visible light in place over a UV passing lens, reflected UV energy will be recorded. Visible colors will be excluded so that the absorbing regions show in exaggerated contrast.

IV. EQUIPMENT

1. Commercial microscopic systems (e.g., Nikon steroscopic microscope SMZ-10 with accessories
2. Floor stands
3. Oblique angle flash lamps for specific microscope photographs
4. Film backs for 35mm, 6x9cm, 4"x5", and Polaroid for instant checks
5. Hassleblad camera with UV barrier filter (EI 1000, and EI 400 color film to record faint emission)
6. Filters over flash tubes to absorb visible energy (liquid cells as before)
7. Optical rail for correct alignment
8. Camera as in 5, with UV transmitting lens and UV bandpass filter
9. Accessories as above
10. High resolution B&W film.

V. TIME REQUIRED

A.	Pre-Shroud in Turin:	1 hours
	On-Shroud in Turin:	8 hours
	At home:	80 hours calibration:
		2 mos. processing:
		2 mos. interpretation
B.	Pre-Shroud in Turin:	1 hour
	On-Shroud in Turin:	6 hours
C.	Pre-Shroud in Turin:	1 hour
	On-Shroud in Turin:	6 hours

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SCORCH EXPERIMENT

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I. OBJECTIVE

We propose to apply approximately ten light scorches to the reverse (nonimage) side of the Shroud along one edge. The temperature of the heating element and its application time will be carefully observed and recorded. Each test area will be limited to about 0.25 cm^2, and the scorches will penetrate the fabric to depths no greater than 50 microns. After each scorch is produced, its ultraviolet fluorescence characteristics will be examined and recorded photographically. The results of this experiment will test scorching against catalyzed cellulose degradation as a hypothesis for image formation.

II. STATEMENT OF THE PROBLEM

One important conclusion of the tests initiated in 1978 is that the image is the product of an oxidation-dehydration reaction. It is not yet known how this reaction was initiated or how it proceeded, although several hypotheses have been proposed. Initially, scorch theories were most discussed, but later interest has focused on the catalyzed degradation of the cellulose by the presence of foreign materials [1-3].

Superficially, the results of the two different mechanisms appear identical, but Miller and Pellicori [3], discount scorches in favor of chemically-induced modification. Their reasons for doing so are based in part on the results of laboratory studies. The image on the Shroud is nonfluorescent as are stains produced on linen by first applying foreign materials (perspiration plus oils, myrrh, and olive oil) and then baking the sample to simulate aging [1]. In contrast to these results, all attempts to produce scorched images in the laboratory have at the same time produced compounds that fluoresce strongly in the yellow-green portion of the visible spectrum [3]. Miller and Pellicori argue that if the Shroud image were a scorch, it too should fluoresce to some measurable degree. They support this argument by noting the conspicuous red fluorescence in those areas of the Shroud that were scorched in the 1532 fire.

Schwalbe and Rogers [4] acknowledged that these observations draw scorch hypotheses into serious question, but they did not accept the nonfluorescent property of the image as conclusive evidence. Fire damage at the so-called poker holes [ref. 4 note 7] does not appear to fluoresce, and it may be that a peculiar chemical makeup of the Shroud fabric inhibits the formation of fluorescent pyrolysis products under certain conditions.

III. METHODS AND MATERIALS

The first phase of this study is to observe and document the fluorescence characteristics of the scorches at the poker-hole locations. Documentation of these areas will include photomicrographs [5] and careful UV-fluorescence photography [5]. In addition to these examinations, we further propose to carry out a short series of semi-destructive tests on the reverse side of the Shroud near one edge. The experiment will involve scorching the cloth at perhaps ten different locations under controlled conditions of time and temperature. The area of each scorch need be no larger than 0.5 x 0.5 cm. The scorch depths will be comparable to that of the image, about 0.05 mm [4,6]; the structural integrity of the fabric will in no way be compromised. To achieve superficial scorches, application times on the order of fractions of a second, as calculated by Jackson, et. al. [7], are anticipated. To apply the necessary heat, we will use a simple soldering iron with a variable-power input. Temperatures can be accurately measured with a chromel-alumel thermocouple and a microvolt meter. Reflectance changes will be restricted to that of the body image [7,8]. Ultraviolet fluorescence will be recorded photographically in a manner similar to that used by Miller [3] during the 1978 study. We hope to enlist the active cooperation of A. D. Adler, S. F. Pellicori, V. D. Miller, R. H. Dinegar, and others interested in this problem.

IV. EQUIPMENT

The equipment required for this study will be compact and highly portable. It will consist of a soldering iron, a variac, a half-meter length of chromel-alumel thermocouple wire, and a calibrated microvolt meter. V. D. Miller and H. W. Johnson will provide photographic documentaion.

V. TIME REQUIRED

A.	Pre-Shroud in Turin:	2 hours
B.	On-Shroud in Turin:	2 hours
C.	At home:	100 hours

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SPECTROSCOPY, UV THROUGH IR ON THE TURIN SHROUD

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I. OBJECTIVE

Obtain more definitive spectra over a wider range of wavelengths than was obtained in 1978. A more extensive system of instrumentation will be employed to obtain spectral absorbance, reflectance and fluorescence on micro- and macro-scale details in blood, body image, scorch, and background regions.

II. STATEMENT OF THE PROBLEM

The spectral content of the various markings on the Shroud is important for conservation, identification, and intercomparison studies.

Reflectance spectra obtained by Pellicori [1] and by Roger and Marty Gilbert [2] in 1978 were invaluable in identifying blood and, in comparison with laboratory simulations, giving clues for the body-image chemistry dicipherment. The proposed more extensive coverage, both spectrally and in physical detail, will concentrate on particular questions such as:

A. In regard to blood stains,
   1. Why are there color differences among and within bloodstain regions?
   2. What is the spectrum of the skin wound stains? Is it like blood?
   3. Identify the different blood spectra - can age, chemistry, exposure, etc., account for the spectral features?

4. How do the spectra of bloodstains compare with those of the various pigments that have been suggested (Fe_2O_3, HgS, etc.)?

B. In regard to body image,
1. Are there detectable differences in spectral absorption of widely separated or specific body image areas?
2. Quantitatively, can subtle differences between scorch and body image be defined?
3. How do the chemical/physical environments - past, present, and future - influence the spectra of the body image?

C. In regard to conservation,
1. What predictions can be made from the spectra relative to conservation questions?
2. Can we obtain absolute spectra on defined areas to serve as reference data to track temporal degradation effects in the future?
3. How do the presence of Ca or other inorganic elements influence the yellowing of the cloth?

III. METHODS AND MATERIALS

Previous spectroscopy measurements on the Shroud have employed reflection techniques and while "noisy" have been consistent with one another and with the chemical testing [3-6]. The noise is inherent in the nature of the object: the color exists only on the surface of the cloth and conventional spectroscopy "sees" the background as well as the surface, "diluting out" the spectrum of interest.

This problem can be minimized by the use of internal reflection spectroscopy [7]. In this technique, incident monochromatic radiation is introduced into one end of a trapezoidal plate in "optical contact" with the surface to be investigated. The angle of incidence is such that the radiation is totally internally reflected. Under such conditions, if the surface to be examined is an insulator, the radiation can be shown to "tunnel" (the "eikonel effect") a few wavelengths into the external medium. The exiting beam therefore presents an absorption spectrum of the surface of the material examined only. Further, the extent of penetration varies with the angle of incidence. Thus one can "test" that he is "seeing" only the surface materials.

No spectra were obtained on details smaller than serveral mm in scale. Using microspectrophotometry, spectra down to several micrometer scale will permit specific resolution of these features. Features such as the skin wounds (scourges) cannot be resolved at that scale. It was found that skin wound and body features were more pronounced at shorter wavelengths than at longer because of the greater relative absorption of these features at wavelengths below 500 nm. The shortest wavelength used in 1978 was 250 nm. The trend of increasing contrast with decreasing wavelength was evident down to at least 350 nm. Photometry and fluorimetry extended to wavelengths below 350 nm should, therefore, provide additional information unobtainable in any other way. Data on "invisible" areas might prove to be crucial in testing image formation processes. Data collection at the sub-nm scale and short wavelengths will permit specific resolution of features.

Similarly, fluorimetry at a small scale and at shorter wavelengths will better define the fluorescent color differences associated with scorch, blood (serum), background and image.

A new instrument, specifically designed to identify hemiporphorin by detecting Soret band absorption, will be built. It will permit rapid global sampling of bloodstains and suspected blood-containing regions. Mapped in this manner, differences in the relative depths of the Soret absorption might be systematically relatable to cloth chemical, exposure, or heating differences with location.

In addition, it would be valuable to map the possible existence of carbonyl and other organic bands using a higher signal-to-noise ratio than was available with the 1978 measurements [6]. Specific comparison of small areas and scorches of different densities will provide quantitative data on the relative degree of oxidative conjugation. This testing will be coordinated with Ercoline's IR studies [8].

Using instrumentation and data handling techniques improved since 1978, reflectance and fluorescence spectra can be taken at a higher signal-to-noise ratio (5 to 10). This should provide more definitive comparison between body, scorch, and control areas. The new data acquisition system is computer based to permit rapid and accurate reduction of spectra. An improved standard of absolute reflectance will be used to refer the spectra to an absolute basis.

Finally, absolute spectra in the 250 to 750 nm range on cm-sized areas on the non-image areas will be taken with which to compare measurements for aging coloration studies, as discussed in another proposal [9].

A tentative schedule of the order of the experiments is shown here. The techniques are independent, however, and any two or three can be operated simultaneously.

a. Microspectrophotometry, 250 to 850 nm on spot diameters at the micrometer scale. Reflection (and transmission) mode.
b. Soret-band photometry, reflection (transmission?) mode of widely distributed blood regions at the mm-scale.
c. Microfluorimetry, over mm-sized areas.
d. Frustrated total internal reflection spectrometry (F-TIRS). Wavelength 250 to 1200 nm at 4 nm spectral bandwidth.
e. IR reflection spectrometry 2 to 14 microns.
f. UV-VIS spectral reflectometry, fluorimetry and possibly transmissometry.

All instruments and techniques are nondestructive. The F-TIRS method, (d), requires contact between the Shroud and the prism.

IV. EQUIPMENT

(Corresponding to above schedule itemization)

a. Leitz instrument provided by RJM (Cambridge Laboratory Technologies).
b. Custom-designed and built fiber optic photometer provided by Pellicori. Filters selected to detect Soret absorption peaks.
c. Same as (a), but including variable exciting wavelength source and scanning visible spectrophotmeter.
d. Gamma scientific instrument provided by McNeil.
e. Nanometrics instrument with cooled detector provided by McNeil.

f. Spectroreflectometer/fluorimeter provided by Gilbert.

V. TIME REQUIRED

Method	a	b	c,d,e	f	(hours)
Setup (Turin)	4	0.5	4	8	
Measurements	8	2	10	12	
In U.S.	400	150	400	200	

All experiments can time-share with other investigators.

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X-RAY DIFFRACTION ANALYSIS

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I. OBJECTIVE

We propose to remove samples of intact threads, image fibrils, and particulate materials from the blood and heel areas for analysis by x-ray diffraction (XRD). Data on threads from fold and nonfold areas will be taken to measure the degrees of cellulose crystallinity and the microscopic effects of stress on the fabric. The bonding structure of calcium to the Shroud cellulose should also be obtained. X-ray diffraction on "blood" materials will test for hypothesized heme structures and the possible inclusions of pigment materials. Finally, measurements from the heel dirt will be taken and compared with those of independent elemental analyses to determine, if possible, the geographical origin of these artifacts.

II. STATEMENT OF THE PROBLEM

There are questions in many areas of Shroud research that can only be answered with x-ray diffraction data. All of these in some way relate to compound structures or bonding configurations. Here, we consider specific issues concerned with the structures of the fabric cellulose, the "blood" artifacts, and the heel dirt.

A. Fabric Cellulose

The focus of most x-ray diffraction research on cellulose is in assessing the state of the intermolecular bonding. Cellulose is a polymer composed of anhydroglucose units. Two of these units combine to form cellobiose, the repeating unit of the chain. Closely packed molecules of cellulose crosslink by hydrogen bonding through the hydroxyl groups. When the arrangement of the crosslinked molecules exhibits a regular, repeating pattern (long-range order), the cellulose is crystalline. Otherwise it is amorphous. Diffraction measurements of cellulose generally show a superposition of patterns characteristic of both crystalline and amorphous materials [1].

The degree of crystallinity is of interest to conservators. Jakes and Sibley [2] note, for example, that crystalline portions are more resistant to acid than are the amorphous portions. Crystalline cellulose is, therefore, less susceptible to hydrolytic degradation and nonspecific oxidizing agents. Even microorganisms attack the amorphous areas of the fiber first.

With x-ray diffraction, the degree of the cellulose crystallinity can be measured on excised thread samples [1]. These data will provide useful general information. By comparing measurements on threads taken from fold

and nonfold areas, we can understand better the microscopic effects that mechanical stress has induced in the Shroud material. We intend to coordinate this phase of the work with the proposed study of the foldmarks by Jackson et al. [3]. This collaboration will specifically include decisions in selecting optimum sample locations and interpreting the combined data.

A further and most interesting possibility for XRD concerns potential information about the image-formation mechanism itself. Schwalbe et al. [4] identified the "chin-band" region at the side of the face as a most critical area for future research. In this region, there is an abrupt discontinuity in the density of the image that seems to correlate with two adjacent lots of warp threads used in the weave. The reason for the discontinuity is not known, but the results from a coordinated series of tests may provide the answer. Here, we propose to include x-ray diffraction as one experiment in this series. If a significant difference exists in the degree of cellulose crystallinity on either side of the discontinuity, x-ray diffraction should reveal it. These results should prove useful in establishing what specific mechanism operated in the image-formation process.

Besides information about the molecular configurations, there is another question to be answered. The x-ray fluorescence measurements of Morris et al. [5] revealed large quantities (ca. 1 wt %) of calcium in the cloth. Heller and Adler [6] later suggested that these represent chelated (ion-exchange bound) forms. Chelated calcium has been known for providing beneficial effects in preserving cellulosic materials [7] although the precise reasons for this are not well understood. With x-ray diffraction we intend to measure the bonding configurations of the calcium to the cellulose molecules. These data will, first of all, test Heller and Adler's explanation for the presence of the calcium [6]. Secondly, the new information should aid textile conservators both in their understanding of the way calcium preserves cellulose and in their evaluation of the effectiveness of these processes in the case of the Shroud.

B. Blood Materials

One of the most controversial issues following the 1978 investigation concerns the composition of the "blood" stains. Heller and Adler [6,8] have given considerable evidence in support of their identification of these stains as actual blood. McCrone [9-11], on the other hand, believes they consist of pigmented materials and not blood. McCrone is led to this conclusion by his observations and measurements of Fe_2O_3, HgS, and materials he identifies as a rose-madder pigment.

The x-ray fluorescence experiment proposed by Schwalbe et al. [4] is designed to test only one point of these competing hypotheses. X-ray fluorescence can show if HgS is present in sufficient quantities to be visually apparent, but it cannot test for the other two pigments. By themselves, elemental analyses for either Fe_2O_3 or rose madder can at best give ambiguous results. Positive tests for iron have already been obtained for the "blood" areas [5], but these are consistent with both blood and Fe_2O_3 hypotheses. Rose madder is a lake pigment with a mordant material of light-element compounds, probably $KAl(SO_4)_3$. The light-elements, if they

can be detected at all by x-ray fluorescence, are not subject to unique interpretations. The question of whether Fe_2O_3 or rose madder are present can best be resolved by x-ray diffraction where identifications are based on sensitive measurements of compound structures.

C. Dirt on Heel

Schwalbe et al. [4] described the potential significance of the dirt on the heel. Sensitive elemental analyses of this material were suggested as a possible way of establishing the geographical origin of the Shroud. Here, we propose that the samples taken for the laser and nuclear microprobes [12,4] first be encapsulated in glass capillaries, subjected to x-ray diffraction, and then released for the elemental analysis. The diffraction measurements will complement the fluorescence data by giving the bonding configurations of the elements present in the sample.

III. METHODS AND MATERIALS

We propose to remove [13] and analyze samples from the following areas on the Shroud:

1. Two non-image threads (each 1 to 3 cm long) from a fold area,
2. Two non-image threads (each 1 to 3 cm long) from a nonfold area,
3. Several (8-10) image fibrils (not threads) from either side of the image density discontinuity in the "chin-band" region,
4. Either two thread segments or approximately 120 μg of particulate material from a blood-stain area, and
5. Approximately 100 μg of particulate material from the "dirt" stain on the heel.

As each sample is taken, it will be immediately sealed in a 0.5 mm Lindemann glass tube. The sample collection will be divided in Turin and the two halves returned to the United States separately by Jenkins and Schwalbe. This will allow joint research to be carried out on the samples at the initial stages and will avoid the danger of loss or destruction of a single collection.

All x-ray diffraction data will be taken with the samples remaining inside their mounts. After the diffraction work is complete, the sealed materials can be removed and used for further testing by other investigators. Samples 1, 2 and 3 will be run on a vacuum, low-angle fiber camera and diffraction patterns recorded. Each pattern will be reduced to a set of "d-spacings" and relative intensity tables. Orientation and line broadening studies will be made on samples 1 and 2 to measure the effects of microstrain on the cellulose crystallinity. These same data will also be used to determine the calcium bonding configurations.

Sample 4 will be used for the studies of the "blood" artifacts. If a "blood" thread is made available, it will be run on both the fiber camera and the powder diffractometer. If the sample consists of particulate materials, these will be run on both the Gandolphi camera and the powder diffractometer. The same procedures will be applied to the heel dirt, sample 5.

IV. EQUIPMENT

None of the x-ray equipment described in the preceding section will be required in Turin. Although all the diffraction measurements are to be carried out in the United States, we will require the aid of Adler and McNeil [13] to collect the particulate samples. For the cutting and removal of threads, we request the assistance of someone appointed by the Archbishop of Turin.

V. TIME REQUIRED

A.	Pre-Shroud in Turin:	4 hours
B.	On-Shroud in Turin:	6 hours
C.	Post-Shroud in Turin:	1 hour
D.	At home:	500 hours

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X-RAY FLUORESCENCE ANALYSIS - A

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I. OBJECTIVE

We propose to conduct a series of direct x-ray fluorescence (XRF) measurements on the Shroud of Turin. This work will refine and supplement existing data on the elemental composition at various locations. The new information will bear primarily on questions pertaining to the preservation of the cloth and on hypotheses for the image-formation mechanism. Specific observations concerning the composition of the blood, water-stain margins and "dirty-heel" area will also be addressed.

II. STATEMENT OF THE PROBLEM

We present a schematic diagram of the proposed experimental apparatus in Figure 1. The general design is similar in several respects to that used in the previous investigation [1]. Once again, the source and detector are mounted together on a portable gantry. This geometry provides adequate stability during the data-collection periods and the capability of fast and accurate repositioning of the system between measurements. A significant improvement over the apparatus used previously [1] is the microcomputer-based analyzer and dual floppy-disc drive. This instrumentation will permit analysis and digital storage of the data on site. Besides this advantage, the experimental design has been improved in several additional respects. Many of these improvements were made in direct response to problems encountered in the earlier work.

Morris *et al.* [1] derived their primary excitation from a secondary-emitter configuration in which a beam of continuous bremstrahlung radiation from an x-ray tube was directed onto a thick tin target. This approach has the advantage of producing small background scattering, but because the incident flux is much reduced from the tube output, the resulting sensitivities are correspondingly small. Also, in the initial study, no effort was made to shield the Shroud from the attached Holland backing cloth; this introduced a certain ambiguity to the results because unique assignments for measured element concentrations are not possible with a double-layer of cloth in the sampling area.

The present design is intended to avert some of the earlier difficulties. With the tube radiation now impinging directly onto the surface of the cloth, a larger primary flux should provide greater

sensitivity. Backing plates of various materials will be attached to long rods and inserted between the Shroud and the Holland cloth. The purpose of an intervening plate is two-fold. The primary function is to isolate the areas of interest on the Shroud from the adjacent backing cloth. Second, we hope with the appropriate choice of material in each case, to use the plate as a secondary emitter so that excitation efficiencies can be enhanced in various energy ranges of interest. An iron or titanium plate, for example, should increase the detection sensitivity for the low-Z elements such as calcium and potassium. In the 9 to 15 keV range, a molybdenum plate would be used, and for higher energies either tantalum or tungsten. The availability of several different materials is desirable to eliminate the specific interferences introduced by any single one. We note in this connection our particular desire to avoid the awkward background interference introduced by the lead shielding and target material in the previous work [1]. Finally, we note that our arrangement also includes radiation shielding to provide safe access to other areas of the Shroud while the x-ray fluorescence experiment is in progress. Radiation in these areas will be monitored with portable detection systems.

In the following subsections, we include discussion of the specific objectives we intend to meet. The individual experiments have been listed roughly in order of their relative importance.

A. General Conservation Studies.

In 1982, Schwalbe and Rogers [2] identified conservation as a primary objective of future testing. The project now has the capability to launch a systematic program of study in this area. There are two problems that should be addressed. The first is to evaluate as completely as possible the current physical condition of the Shroud. The second problem is to establish measures that should be taken to preserve the integrity of the cloth and its image.

X-ray fluorescence is one of several nondestructive tests that should be included in any systematic program of conservation. The results that Morris et al. [1] obtained in 1978 have already proven the technique potentially useful. Specifically, their measurements showed large and relatively uniform distributions of calcium in all investigated areas. Heller and Adler later identified the calcium as an ion-exchange-bound form, and Druzik pointed out its beneficial effect in preserving cellulosic materials. The presence of calcium in this form inhibits certain types of cloth degradation that eventually discolor and embrittle the material. In 1978, the Shroud was observed to be in generally good condition; that is explained, at least in part, by the calcium first measured by x-ray fluorescence.

The experimental design of the earlier study did not permit sensitive analyses of energy range below 5 keV. (Calcium, at 3.7 keV, was observed because of its presence in relatively large quantities.) Except for calcium, the presence and distribution of additional low-Z elements remains completely unknown. It would be important, for example, to look for magnesium, which has buffering characteristics similar to those of calcium. The present experiment is designed to allow a gaseous helium backfill to the volume enclosed by the radiation shielding. The helium environment will

reduce attenuation of low-energy x-rays and permit more sensitive analyses of the low-Z elements.

We intend to carry out our conservation study in close cooperation with Druzik of the Los Angeles County Museum of Art. Our x-ray fluorescence results will be correlated with those of surface pH measurements [3], UV-VIS transmission and reflectance data [4] from the same sample areas, and we shall analyze the spots involved in the on-site artificial aging experiment [5]. The combined information should contribute substantially to an evaluation of the physical condition of the cloth. The program following this work depends on the results of the study. In the data analysis, we will be looking specifically for a correlation between small quantities of calcium and advanced stages of degradation. If a significant correlation is observed, it should then be possible to identify locations on the Shroud that are particularly susceptible to continuing damage and devise appropriate steps to arrest the process.

B. Image-Formation Mechanism.

The image is now known to reside as a chemical modification of the cloth rather than as an applied pigment. Heller and Adler [6] postulate the image is a product of an oxidation-dehydration reaction, but the actual formation mechanism is still unknown. With respect to the entire problem of image formation, we feel the most critical area for future investigation is the so-called "chin-band" region located at the side of the face. There, a discontinuous distribution occurs in the image density, one that appears to correlate with a difference in the sample lot of the warp thread rather than with any structural (or anatomical) feature of the model assumed to be used in the transfer process [2]. The observation suggests that either the chemical or surface characteristics of the textile affected the image-formation process in some way.

As we mentioned, there are no totally satisfactory hypotheses for how the image arrived on the cloth. However, an interesting possibility is that a dehydration reaction was catalyzed locally by foreign materials transferred to the surface, perhaps by contact with an actual corpse [7,8]. One difficulty with this hypothesis is the superficial distribution of the image color. Direct microscopic observations in the image areas reveal yellow fibers on the crowns of the threads. Only the top three or four layers of fibers are discolored. If a nominal diameter of 15 microns is taken for the linen fibers [2], we obtain an approximate image depth of approximately 50 microns. Even a viscous liquid would, presumably, wet the material to depths greater than this and produce a "deeper" image than that observed. To counter this objection, Druzik (cited in reference [2]) has suggested that chelated calcium [6] in large concentrations may have buffered the reaction in the deeper portions of the threads and, thereby, confined the discoloration to only a few of the topmost surface fibers.

We intend to examine the chin-band area with x-ray fluorescence to see if there are significant differences between the elemental contents of the light and heavily-colored image regions. A large difference in calcium, or perhaps, magnesium would support Druzik's argument. At the same time, our measurements would test other hypotheses. Jakes and Sibley [9] note that oxidation of cellulose is catalysed by transition metals such as cobalt, iron, and manganese. Carter [10] observed that chelated iron enhanced the

rates of degradation in cloth exposed to low-energy x-rays and heat. X-ray fluorescence provides a sensitive probe for all of the transition elements in question. The data will test whether the discontinuity in image density is the result of some difference in heavy-element concentrations.

In our proposal for conservation studies, we suggested the adoption of a coordinated approach to the general problem. Here again, we recommend that other tests also be conducted in conjunction with our own. In particular, these should include x-ray diffraction [11] on fiber samples taken from the chin-band region to establish any differences in the degrees of cellulose crystallinity. Infrared spectrophotometry [4] and extensive photomicrography [12] should also be applied specifically to probe the surface characteristics of the material there.

Finally, we intend to repeat the measurement scan that Morris et al. [1] made across the face. McCrone [13,14] postulates that particulate Fe_2O_3 constitutes most of the image density. If this is true, we would expect to see a correlation between iron and the reflected optical density of the image. The early x-ray fluorescence data were examined for this effect, and a correlation is suggested by the results. However, the precision of these data is not sufficient to test the hypothesis definitively. We, therefore, propose to repeat the experiment and obtain the precise data necessary to settle the question.

C. Mecuric Sulfide in the Blood Areas.

There is still some confusion about the composition of the blood stains despite a considerable body of evidence supporting its identification as actual blood [6,15]. McCrone [16] described several methods he used to identify HgS in selected particles recovered from the side-wound area. He claims this finding proves that vermillion is a significant component of the "blood". McCrone interprets this finding as a tell-tale product of an artist's forgery. Others dispute this claim; Heller and Adler [6] state that vermillion is not present in significant amounts.

Interestingly, McCrone [16] and Heller and Adler [6] base their opposite opinions on microanalytic observations of the same collection of tape samples. The unresolved question, therefore, calls for independent observations. Earlier, x-ray fluorescence data [1] were taken at the side wound, but these measurements lack the precision necessary to settle the matter. The problem with the 1978 results was a large background interference in the energy range between 9 and 13 keV. The source of the difficulty was identified as an interference from the lead collimator and the target material.

These problems have since been eliminated. With the present system, we can provide definitive evidence. If vermillion had been used as a pigment, there should be a sufficient amount of material there to be visible. Preliminary estimates, based on reflectance measurements of Fe_2O_3, suggest a minimum quantity of mercury that could be present and consistent with the 1978 data is on the order of 10 $\mu g/cm^2$. This amount is well within the resolution of our instrumentation. Mercury will be detectable in areal weight concentrations of 1 $\mu g/cm^2$ or less.

D. Water-Stain Areas.

The low-energy radiographs of Mottern et al. [17] reveal clear and distinct images of the water-stain margins. This observation is quite surprising in view of the absence of significant radiographic density in the blood areas. The elemental composition of the water margins is not presently known. Heller and Adler [6] observed significant quantities of particulate Fe_2O_3 on sticky-tape samples from these areas, but these surface samples do not necessarily represent the bulk composition. X-ray fluorescence will provide quantitative measures of the elements in these areas.

The question of the water-stain composition bears on an unresolved controversy between McCrone [13,14] and Heller and Adler [6]. The debate is one of data interpretation and centers on the identification of the red particles observed on the tape samples. Those identified as Fe_2O_3 by Heller and Adler [6] were found predominantly in the water-stain areas. To explain their presence, the authors postulate a mechanism that predicts the margins to contain high concentrations of iron compounds. Our x-ray examination will test this hypothesis. A substantial concentration of iron would corroborate the proposed mechanism of Heller and Adler. However, if normal background quantities are observed, the entire question of the origin of the Fe_2O_3 will likely have to be reconsidered.

E. Dirt on Heel.

The microscopic survey of Heller and Adler [6] revealed a large variety of materials on the sticky-tape samples. These included an assortment of incidental debris (insect parts, pollen, spores, wax, etc.) that obviously represent the accumulation of many centuries. But, in addition to these, there are some materials that likely date to the time of the formation of the image or earlier. The blood artifacts are an obvious example. These have been studied in detail and continue to be the focus of ongoing research. But some think that one other, the dirt contamination on the heel, may date from the same period as well.

A study of this material has some intriguing potential. If the Shroud had been an actual burial cloth, and if the image somehow resulted from the presence of a corpse, it is quite reasonable to suppose that this area was stained by dirt transferred from the heel of the body. The foreign material would then represent a sample from the location where the corpse was interred.

We propose to measure the heel area with x-ray fluorescence to determine the major components of the stain. But, because there is only a small amount of dirt present, it is likely that little quantitative information can be obtained about the concentrations of trace elements. Therefore, in addition, we plan to remove a small amount, perhaps 50 micrograms of material depending on the size and visual similarity of the individual particles, and submit them to further analysis with more specialized equipment. The ideal instrumentation for the follow-up study is the nuclear microprobe described by Maggiore [18]. The nuclear microprobe consists of a Van de Graaf accelerator that generates a nearly monochromatic beam of highly energetic, light ions (protons, deuterons, tritons, helium-3

Proposed X-ray Fluorescence Apparatus - Schematic

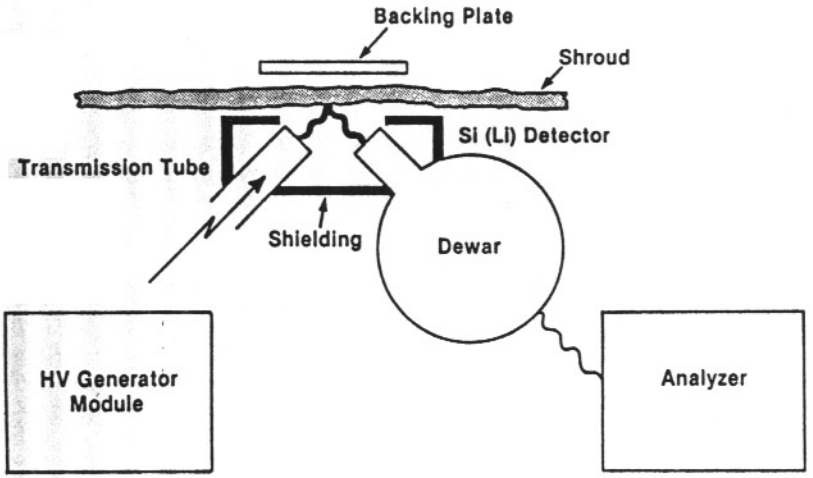


FIGURE 1

Schematic diagram of the source-sample-detector geometry. The source and detector are fixed rigidly on a movable ganty. Backing plates will be used to isolate the sample area on the Shroud from the adjacent Holland cloth. Radiation shielding will permit safe access to other areas on the Shroud while x-ray measurements are in progress.

ions, and alpha particles). The beam is focussed with a superconducting magnet to obtain spatial resolutions of 5 microns or better. Trace elements can be measured at concentrations of 1 to 10 ppm.

We submit that if the trace-element levels are known, it would then be possible to compare these with results of similar analyses of clay samples from various localities in Europe and the Middle East. A data base for this research should be available from elemental analyses of ceramic artifacts from these areas [10]. Ceramics can usually be located quite accurately both geographically and temporally on the basis of stylistic considerations. If a "fingerprint" match were made, the result would stand as strong evidence for the geographical origin of the Shroud. This study would be coordinated with those of Heller [19], McNeil/Adler [20], and Bucklin [21] who propose to investigate the heel dirt with other techniques.

III. METHODS AND MATERIALS

X-ray fluorescence is a well-known and widely-practiced nondestructive technique [22]. Standard procedures have been established for XRF analyses and will be followed in this series of experiments. However, because of the special nature of this problem, we offer a step-by-step description of the procedure we intend to follow in Turin.

Before each measurement, a metal backing plate is first placed behind the test point between the Shroud and Holland cloth, and its supporting rod clamped at the side of the table. The source-detector assembly is then positioned directly in front of the area to be examined with the open end of the radiation shield in light contact with the cloth. The x-ray tube is turned on and the area monitored for possible radiation leaking from the shield. If an unacceptable level of radiation is observed, all necessary adjustments are made to eliminate the hazard. After these steps are completed the detection-counting system is started. Counting proceeds from preset times ranging from 10 to 200 minutes depending on the particular test and the degree of precision desired. At the end of each measurement, the x-rays are turned off and the source-detector system rolled back, away from the cloth surface. As a final step, the data are recorded onto floppy-disc memory.

In the above procedure, we mentioned that some limited physical contact would be required between the apparatus and the cloth. On the image surface, the radiation shield encloses the test area (see Figure 1). The contacting surface of the shield will consist of either metal, plastic, or teflon. During each measurement, the shield rests against the surface of the fabric, but virtually no pressure is placed on the cloth because the weight of the system is supported by the floor and the Shroud is held in an upright position. For measurements at low energies, the shielding volume will be backfilled with the clean helium gas. Neither the limited physical contact we describe nor the helium environment will produce any damage to the cloth or its image.

On the nonimage surface of the Shroud, contact will be made with backing plates of various materials. To insert these between the Shroud and Holland cloth, short lengths (20 cm) of stitching must be removed at several places along the edges. A similar detachment was performed in 1978 to permit access for the vacuum probe, and we propose that Riggi again supervise this operation.

Finally, we assure that no radiation will result from our experiment. High-energy (greater than 10 keV) excitation is safe to use on the linen fabric [1,17], and most of the proposed work will be conducted in the high-energy regime. However, at very low energies (less than 1 keV) some precautions may be necessary [10]. Before we begin any measurements where radiation damage might occur, we will examine the ranges of x-ray energies and intensities to find safe working parameters. We believe that problems at the very low energies can be eliminated, but if we discover that any dangers remain, this portion of the planned testing will be aborted.

Finally, the studies proposed here will be coordinated with the XRF work package proposed by Carter et al. [23] which addresses essentially different issues.

IV. EQUIPMENT

EDAX will provide the instrumentation for the tests and the equipment to be used in Turin is presently under construction. The investigators will provide their thin-sample standards and radiation monitoring equipment. We will require the assistance of Adler and McNeil [20] to collect the particulate samples from the heel area.

V. TIME REQUIRED

A.	Pre-Shroud in Turin:	4 hours
B.	On-Shroud in Turin:	48 hours (in 4 blocks of 12 hours)
C.	Post-Shroud in Turin:	12 hours (calibrations and controls)
D.	At home:	200 hours

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X-RAY FLUORESCENCE ANALYSIS-B

PRINCIPAL INVESTIGATOR: G. F. Carter, Ph.D.
Eastern Michigan University

COINVESTIGATORS: E. J. Jumper, Ph.D.
Air Force Institute of Technology

and

G. W. Carriveau, Ph.D.
Detroit Institute of Arts

I. OBJECTIVE

We propose to conduct a series of x-ray fluorescence analyses on the Shroud of Turin. This work will supplement the work package by Schwalbe, Jenkins, and Riggi. The major emphasis will be the determination of light elements, particularly silicon, phosphorus, sulfur, chlorine, potassium, and calcium. Areas investigated will include several blood areas, body-image areas, background areas, and specific areas such as the nose, fingers, heel, hips, eyes, shoulders, and hair. Problems addressed are primarily how the above elements were transferred to the Shroud, whether by direct contact with a body, by means such as painting, or by adventitious contamination.

II. STATEMENT OF THE PROBLEM

We propose to use a Kevex 0750 instrument which has been specially designed for use with archaeological objects of any shape. This instrument has full capabilities of determining both heavy and light elements (greater than atomic number ten or eleven) by energy-dispersive X-ray fluorescence (XRF). The lower limits of detectability have recently been determined on a group of doped linen specimens containing known weights of Si, P, S, Cl, K, and Ca. Lower limits of detectability have been determined for these same elements and also for Fe and Hg using wavelength dispersive XRF. These experimental results enable us to estimate the capability of the Kevex 0750 instrument. In the future, we will be able to calculate quantitatively the amounts of various elements on the Shroud.

Recent experimental work using XRF has also been carried out on linen specimens doped with blood, saliva, or urine to determine the rates of migration of several elements in various body fluids on linen exposed to 100% relative humidity. This work has provided an understanding of which elements may migrate on linen in the presence of humidity. This information should prove useful in interpreting the XRF analyses, which will comprise the concentrations of various elements in specific locations on the Shroud and the variations in concentration from one type of area to another.

Elements on the Shroud (other than C, H, or O) must have originated from one or more of the following sources: (1) the linen (i.e., in the uptake of elements from soil) or the treatment of the linen (e.g., during retting); (2) contact with a body; (3) deliberate additions by man (e.g., painting, dyeing, rubbing, or staining); or (4) adventitious contamination throughout the lifetime of the Shroud. XRF analysis should facilitate the determination of the source of elements now found on the Shroud.

We propose to investigate the following questions using XRF which will be coordinated with the proposed XRF Studies of Schwalbe, Jenkins, and Riggi [1].

a. What is the elemental composition of the blood areas compared with the halo areas surrounding the blood areas and with nearby body-image areas?

Blood areas for investigation include the side wound, the wrist wound and arms, the foot wound, and the hair. Of particular interest will be the halo areas surrounding the blood areas. If these areas are due to the transfer of whole blood and/or body fluids to the cloth, they should contain those elements that probably do not migrate over very long periods of time, such as iron, sulfur, and phosphorus. Other elements, such as potassium (which may easily be determined in very low concentrations by XRF), calcium, and chlorine may not migrate completely, so they will also be of interest. Detection of non-migrating elements from body fluids in the halo areas would indicate probably a natural origin for these elements rather than from a man-made simulation of a shroud. The absence of halos of body fluid deposits surrounding blood in the hair or blood that has run down the arms would also be important because this would indicate that the halos were likely caused by body fluids exuded along with blood rather than the separation of blood into various components. The presence of halos of body fluid materials surrounding some types, but not all, of blood areas would be telling evidence that no one smeared blood, etc., on the Shroud.

The above information should be useful in confirming that blood and body fluids were naturally deposited on the Shroud in the blood and halo areas, as believed by Heller and Adler [2], if, indeed, this is the case.

B. What is the elemental composition of the body-image areas compared with background areas, including the side of the cloth?

Since it has been suggested by McCrone [3] that the body images were made from iron oxide or mercuric compounds, the compositions of the body images will be compared with the compositions of background areas, including the sides of the cloth. The concentration and distribution of pigmented materials, if present, will be measured to determine whether these are primarily adventitious contaminants. Body-image areas will also be studied to determine whether there is evidence for the presence of body fluids or other materials that may have directly transferred to the Shroud. These tests will relate to whether the image was formed by physical contact or by painting, etc.

C. What is the elemental composition of the scourge-mark areas compared with blood, halo, body-image, and background areas?

XRF analysis of scourge marks should help to determine whether blood and body fluids or other materials were transferred to the Shroud in the

scourge-marked areas. If pigments are present in these areas, XRF analysis should certainly detect their presence.

D. What is the elemental composition of the area between the dorsal hips compared with blood, halo, and body-image areas?

The dark image between the dorsal hips may be a residue from feces. If this is true, then XRF analysis could determine the presence of certain elements, particularly P and S, and perhaps other elements in this area. Verification of transfer of fecal material from the body to the Shroud in this area would be a further strong argument that the Shroud had indeed been in contact with a dead body rather than produced by a painter. If significant differences are detected from this area and the adjacent body image, we shall recommend samples be taken [4] for subsequent chemical assay for hypothetical fecal material.

E. What is the elemental composition of the finger areas compared with that of body-image and background areas?

Carter has suggested that perhaps the "too-long" fingers on the Shroud image may be due to x-rays emanating originally from bones in the hands [5]. However, an alternate suggestion is that perhaps these darker areas at or below the base of the fingers are materials that have been transferred to the cloth, such as blood or dirt. XRF analysis should be able to determine whether these areas are similar to other body images or whether they comprise some sort of deposited material.

F. Do the shoulder and calf (leg) areas of the Shroud contain deposits of dirt similar to the heel area?

XRF analysis should be able to indicate the amount of silicon (and possibly other elements such as aluminum or titanium) present in the heel area, which is purported to contain appreciable particles of dirt. Further the shoulder and calf (leg) areas should be analyzed by KRF: if dirt were transferred to the Shroud from a body, one would expect the dirt to be in higher concentrations in areas where a person would tend to accumulate dirt and also where the greatest pressure would have been exerted on the Shroud by the body.

G. What is the variation in elemental composition of body-image area as a function of image intensity?

XRF should be capable of determining whether materials have been transferred to the Shroud in the body-image areas. If pigments were used in these areas, certainly the sensitivity of XRF is great enough to determine the presence of most elements found in even trace quantities of pigments. A correlation should then be found between the concentration of a given element and the visible intensity of the body image. Specific areas of interest include the tip of the nose, the eyes, the beard, and areas of lower image intensity.

H. What is the variation, if any, of the elemental composition of the background?

XRF analysis should be able to indicate the levels of elements that were present originally in the linen plus those that have migrated from

other areas. It is expected, but should be confirmed, that these areas will all have the same composition. For instance potassium is determined with great sensitivity by XRF, and its concentration and distribution in the side and off-image areas should be easily determined by XRF.

I. Is sodium chloride responsible for helping to preserve the Shroud from deterioration?

If the Shroud linen had originally been intended for use as a Shroud, it may well have been deliberately treated in a dilute preservative solution of sodium (or perhaps calcium) chloride or nitrate. Although XRF is not very sensitive in determining sodium, it has excellent sensitivity to calcium and moderate sensitivity to chlorine. The overall levels of calcium and chlorine (as well as sodium, which could be determined by another method) may be measured using XRF and the standard doped linen specimens prepared by Carter.

III. METHODS AND MATERIALS

Because the Kevex 0750 machine has been routinely used for three years (and a similar model for five years previously) to analyze archaeological and museum objects, we anticipate no difficulties in using this machine to analyze the Shroud. The machine is built to be mobile and, therefore can be moved and positioned to analyze any area of interest without unnecessarily disturbing the Shroud. A helium atmosphere will be used during the determination of all light elements. Because the power for the x-rays is low, no damage has occurred to linen (i.e. no detectable discoloration due to x-rays) in an exposure of 100 hours. (However, when one uses high intensities of x-rays, such as in wavelength dispersive XRF, then linen may be discolored by the x-rays, even in five minutes).

Additional testing prior to Turin will be carried out to ensure further that no damage will be imparted to the cloth. Counting times will normally be 600 or 1000 seconds, but different secondary targets necessitate three or perhaps four separate spectra at each location. The diameter of the area analyzed is 8mm, but the diameter may be changed for improved spatial resolution. A back-up plate will be positioned behind the Shroud but in front of the backing cloth attached to the Shroud, as in Schwalbe et al. [1]. This should prevent any x-rays from the backing cloth from being detected. For light elements, there is a low probability that x-rays from the backing cloth would be able to pass through the Shroud because they are very readily absorbed by matter.

The spectra will be recorded on floppy discs; however, a visual display of the spectra being accumulated and qualitative and quantitative programs in the system will provide instant knowledge of the amounts or elements being detected. This should be most helpful in making on-the-spot adjustments in our procedures.

IV. EQUIPMENT

The Kevex 0750 machine has demonstrated its usefulness in archaeological applications in the laboratory of the Detroit Institute of Arts [6-9]. The machine uses a primary x-ray tube with various secondary targets; the secondary targets are used selectively to enhance the sensitivity for certain groups of elements, such as the light elements.

However, using a number of secondary targets involves three or possibly four determinations at each spot (location) on the Shroud to obtain information on a wide range of elements.

The use of two XRF machines [1] in Turin has several advantages: (1) an increased capability to carry out more analyses in a limited time, (2) complementary abilities by different machines (usually one machine will excel in determining certain elements while the other will excel for a different set; the relative capabilities of the machines will be tested in advance of the experiments in Turin), (3) back-up capabilities in case of breakdown of either machine (as did happen to the XRF experiment in 1978), (4) cross-comparison of analyses for improved results.

Kevex will arrange for the transportation of the 0750 unit to Turin, and a technician will be available for solving any problems that might arise during the use of the machine in Turin. Standard linen specimens have already been prepared by the investigators, and analysis has started at this time. Incidental equipment such as a radiation monitor will be supplied by the investigators.

V. TIME REQUIRED

It is estimated that one hour will be necessary for determining the elements of interest at each location. Although the minimum estimated time required for the XRF determinations described in this proposal is 48 hours, it is advisable, if at all possible, to allow up to 100 hours. The time requirements, however, could be fulfilled while different experiments are being carried out at other locations on the Shroud (e.g., micro-sampling or XRF analysis by the other machine).

A.	Pre-Shroud in Turin:	4 hours
B.	On-Shroud in Turin:	48 hours (4 blocks of 12 hours)
C.	Post-Shroud in Turin:	12 hours
D.	At home:	200 hours

VI. REFERENCES

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APPENDIX A

STURP Agreement Form

THIS AGREEMENT made and entered into on

198 , by and between THE SHROUD OF TURIN RESEARCH PROJECT, INC., a non-profit corporation organized under the laws of the State of Connecticut with a place of business in Amston, Connecticut (hereinafter referred to as "STURP"), and _____, (hereinafter referred to as "MEMBER");

W I T N E S S E T H:

WHEREAS, STURP has performed scientific tests on the Shroud of Turin; and

WHEREAS, MEMBER desires to be a member of STURP and to participate in the performance and interpretation of tests on the Shroud of Turin;

NOW THEREFORE, in consideration of the sum of one dollar ($1.00) and other good and valuable consideration, receipt of which is hereby acknowledged and in consideration of the execution of agreements identical or similar to this agreement by other individuals desiring to participate in the performance and interpretation of the scientific tests and in consideration of the premises and covenants contained herein, the parties hereto agree as follows:

1. MEMBERSHIP. The MEMBER whose name appears above is officially a member of STURP and may hold himself out to the public as such as long as this agreement shall remain in full force and effect.

2. DUTIES. The MEMBER shall devote so much of his time, effort, knowledge, ability and expertise as he is able and willing in the performance and interpretation of the scientific tests on the Shroud of Turin.

3. COPYRIGHT. The parties hereto agree that the copyright for all materials created by the MEMBER in the performance and interpretation of the tests upon the Shroud of Turin shall be jointly owned by STURP and MEMBER. Said materials shall include, but are not limited to, all written, oral, photographic or film recordation of the performance and interpretation of said tests. Said copyright ownership shall apply to all such materials created by the MEMBER in conjunction with the work of STURP from July 14, 1978. It is further agreed that neither party to this agreement shall deny access to the other of the material held in joint copyright.

4. CONFIDENTIALITY. Those things which pertain to STURP, including STURP and individual research activities, will be held confidential by every

EMBER of STURP unless the MEMBER receives written notification dicating approval of the Board of Directors of STURP to particular sclosure of information or material. This provision regarding nfidentiality shall continue in full force and effect for a period of three ;) years from the date of the next STURP expedition to Turin.

ACADEMIC FREEDOM. In pursuit of scientific knowledge concerning ıe Shroud of Turin, no MEMBER of STURP or STURP collectively will be ənied freedom of research or thought.

BENEFIT AND BINDING EFFECT. This agreement shall inure to the ənefit of and be binding upon the parties hereto and their heirs, ıccessors and assigns.

GOVERNING LAW. This agreement shall be governed by and construed accordance with the law of the State of Connecticut.

SEVERABILITY. The invalidity or unenforceability of any provision ereof shall in no way affect the validity or enforceability of any other ovision.

IN WITNESS WHEREOF, the parties hereto have set their hands and ıls, STURP acting herein by its duly authorized officer, all as of the day ıd year first written above.

THE SHROUD OF TURIN RESEARCH PROJECT, INC.

BY _____

MEMBER

SIGNATURE _____
PRINT NAME

APPENDIX B

PUBLISHED SCIENTIFIC PAPERS OF STURP

Before 1978 Examination

1. Proceedings of the 1977 United States Conference of Research on the Shroud of Turin.

   a. Accetta, J., "Infrared Thermography with Applications to the Shroud of Turin".

   b. Accetta, J., "X-Ray Fluorescence Analysis with Application to the Shroud of Turin".

   c. Devan, D.; Jackson, J.; Jumper, E., "Computer Related Investigations of the Holy Shroud".

   d. Devan, D., "Photography of the Turin Shroud for Use in Image Analysis Experiments".

   e. German, D., "An Electronic Technique for Constructing an Accurate Three-Dimensional Shroud Image".

   f. Jackson, J., "Color Analysis of the Turin Shroud: A Preliminary Study".

   g. Jackson, J., "A Problem of Resolution Posed by the Existence of a Three-Dimensional Image on the Shroud".

   h. Jackson, J.; Jumper, E.; Mottern, W.; Stevenson, K., "The Three-Dimensional Image on Jesus' Burial Cloth".

   i. Janney, D., "Computer-Aided Image Enhancement and Analysis".

   j. Jumper, E., "Considerations of Molecular Diffusion and Radiation as an Image Formation Process on the Shroud".

   k. LaRue, R., "Tonal Distortions in Shroud Image Photographs".

   l. Lorre, J. and Lynn, D., "Digital Enhancement of Images of the Shroud of Turin".

   m. Rogers, R., "Chemical Considerations Concerning the Shroud of Turin".

2. 1978 II Congresso Internazionale di Sindonologia - La Sindone E La Scienza.

   a. Bucklin, Robert, "A Pathologist Looks at the Shroud of Turin".

b. Jackson, J. P. and Jumper, E. J., "Space Science and the Holy Shroud".

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APPENDIX C

STURP RESUMES

1. ALAN D. ADLER; born 5 Oct 1931; PhD (Chemistry) University of Pennsylvania, 1960; BS (Chemistry) University of Rochester, 1953; Research Experience: pyridine hemin, stoichiometry, heme compounds, porphyrins, colligative properties, reticuloendothelial system. Professional Positions: Western Connecticut State University (Professor), New England Institute. Specialty: Chemistry. Professional Societies: American Chemical Society, American Physical Society, American Association for the Advancement of Science, American Society of Photobiology, American Association of Clinical Chemists, Sigma Xi, New York Academy of Sciences, American Association of University Professors, Phi Lambda Upsilon.

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1. Heller, J. and Adler, A., "Blood on the Shroud of Turin," Applied Optics, 19, 1980, p 2742.
2. Heller, J. and Adler, A., "A Chemical Investigation of the Shroud of Turin," J. Can. Soc. Forensic Science, 14, 1981, p 81.
3. Jumper, E.; Adler, A.; Jackson, J.; Pellicori, S.; Heller, J.; and Druzik, J., "A Comprehensive Examination of the Various Stains and Images on the Shroud of Turin," Archaeological Chemistry III, Advances in Chemistry Series of the American Chemical Society, 1983.

Number of Professional Publications, 55; Presentations, 25.
Mailing Address: Professor of Chemistry, Western Connecticut State College, Danbury, CT 06810, USA.
Telephone: Home -- (203) 938-2920; Business -- (203) 797-4243.

2. CHARLES CHILES AVIS; MA (Astronomy) University of Texas at Austin, 1976; BA (Physics) Rice University, 1973; Research Experience: gamma-ray astronomy, digital image processing, support for Voyager Jupiter mission, narrow-band differential photometry. Professional Position: Jet Propulsion Laboratory. Specialty: Physics.

Shroud Publications:

1. Avis, C.; Lynn, D.; Lorre, J.; Lavoie, S.; Clark, J.; Armstrong, E.; Addington, J., "Image Processing of the Shroud of Turin", IEEE 1982 Proceedings of the International Conference on Cybernetics and Society, #0360-8913/82/0000-0554, pp. 554-558, October 1982.

Number of Professional Publications, 10.
Mailing Address: 503 E. Claremont St., Pasadena, CA 91104, USA.

3. ROBERT VAN ZANDT BUCKLIN; born 24 Jun 16; MD, Loyola University School of Medicine, 1941; JD, South Texas College of Law, 1969; BSM, Loyola University, 1938; Research Experience: Paraffin Embedding, Carcinoma of Cervix, Medical Aspects of Crucifixion of Christ, Umbilical Arteries, Well Water Nitrates and Methemaglobinemia, Unilateral Twin Tubal Pregnancy, Adenoma of Anal Gland, Maxillary Extension of Retinoblastoma, Heart Disease, Drowning, Identification of Human Remains. Professional Positions: San Diego County Coroner, Los Angeles Country Coroner - Medical Examiner (Acting Chief), Harris County Texas (Deputy Chief Medical Examiner), Travis County Texas (Chief Medical Examiner). Specialty: Forensic Medicine (Pathology). Professional Societies: American College of Physicians, American Society of Clinical Pathologists, American Academy of Forensic Sciences, American College of Legal Medicine, Texas Bar, Pittsburgh Institute of Legal Medicine, National Association of Medical Examiners.

Shroud Publications:

1. Bucklin, Robert, "A Pathologist Looks at the Shroud of Turin," La Sindone E La Scienza, Edizone Paoline, Turin, Italy, 1978.
2. Bucklin, Robert, Afterword to Verdict on the Shroud, Servant Books, 1981.
3. Bucklin, Robert, "The Shroud of Turin" Viewpoint of a Pathologist," Legal Medicine 1982, W. B. Saunders Co. Reprinted in Shroud Spectrum Volume 5, 1982, and Journal of Mississippi State Medical Association, May 1983.

Number of Professional Publications, 33.
Mailing Address: 5567 Calumet Avenue, La Jolla, CA 92037, USA.
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4. WILLIAM J. CAIRNEY, PhD (Medical Microbiology) Cornell University, 1977; MS (Mycology) Cornell University; BA (Biochemistry) Rutgers University, 1966; Research Experience: effect of hyperbaric oxygen therapy on pathogenic microorganisms, microbial degradation of military herbicides, human factors in aircraft operations. Professional Position: Air Force Academy (Deputy Head of Biology Department). Specialty: Microbiology.

Number of Professional Publications, 18.
Mailing Address: HQ USAFA/DFB, USAF Academy, Colorado Springs, CO 80840, USA.
Telephone: Business (303) 472-2720.

5. GARY WALTER CARRIVEAU; born 6 Aug 1939; PhD (Atomic Physics) Australian National University, Canberra, 1970; MS (Physics) San Diego State University, 1967; BS (Physics) San Diego State University, 1965; Research Experience: technical analysis of works of art and archaeological objects, thermoluminescence dating, radio-carbon and fission track analysis, various X-ray techniques, spectroscopy, low energy nuclear structure, thermalization, and scattering. Professional Positions: Detroit Institute of Arts, Wayne State University (Adjunct

Professor), Metropolitan Museum of Art, Pennsylvania Museum Applied Science Center for Archaeology. Specialty: Atomic Physics.

Number of Professional Publications, 70.
Mailing Address: 3420 Cambridge, Detroit, MI 48221, USA.

6. GILES F. CARTER; born 22 Mar 30; PhD (Physical Chemistry) University of California at Berkely, 1953; BS (Chemistry) Texas Tech University, 1949; Research Experience: crystal structure, X-ray fluorescence, chemical analysis of coins, adhesives, diffusion coatings. Professional Positions: Eastern Michigan University (Professor), E.I. DuPont de Nemours and Co., University of California Radiation Laboratory. Specialty: Chemistry. Professional Societies: American Chemical Society, American Society for Metals, American Numismatic Society, Royal Numismatic Society, Society for Archaeological Sciences, Sigma Xi.

Shroud Publication:
1. Carter, G. F., in Archaelogical Chemistry III, American Chemical Society Advances in Chemistry Series (1984).

Number of Professional Publications, 41; Presentations, 32.
Mailing Address: Chemistry Department, Eastern Michigan University, Ypsilanti, MI, USA.
Telephone: Home -- (313) 483-7527; Business -- (313) 487-2039.

7. MICHAEL JOSEPH DENIRO; born 22 Mar 1949; PhD (Biochemistry) California Institute of Technology (Pasadena), 1977; BS (Chemistry), University of Notre Dame, 1970; Research Experience: geochemistry, geological, archaeological, and planetary sciences. Professional Positions: University of California at Los Angeles (Assistant Professor), California Institute of Technology (Post Doc.). Specialty: Geochemistry.

Number of Professional Publications, 26; Presentations, 32+.
Mailing Address: 2809 Geology Building, University of California, Los Angles, California 90024, USA.
Telephone: Business -- (213) 206-6388.

8. ROBERT HUDSON DINEGAR; born 18 Dec 1921; BA (Theology/Philosophy) College of Santa Fe, 1976; PhD (Physical Chemistry) Columbia University, 1951; MA (Chemistry) Columbia University, 1947; Certificate in Meteorology, New York University, 1943; BA (Chemistry) Cornel University, 1942; Research Experience: chemical and physical properties of explosives compounds. Professional Position: Los Alamos National Laboratory. Specialty: Chemistry. Professional Societies: Sigma Xi; Phi Lambda Upsilon; American Institute of Chemists (Fellow, Certified Professional Chemist); American Chemical Society; New York Academy of Sciences; New Mexico Academy of Sciences (Fellow); American Meteorological Society (Professional Member).

Shroud Publications:

1. Dinegar, Robert H, "Pastoral Aspects of Research on the Shroud of Turin," Proceedings of the 1977 United States Conference on Research on the Shroud of Turin, K. Stevenson, Ed., Albuquerque, NM, March 23-24, 1977, pp 20-23.

2. Dinegar, Robert H., "Operation STURP: The Shroud of Turin Research Project," The Living Church, 178 No. 9, March 4, 1979, pp 9-10/15.

3. Dinegar, Robert H., "Toward Unhoaxing the Turin Shroud," The Living Church, 180 No. 6, February 10, 1980, pp. 9-11.

4. Dinegar, Robert H., "The Shroud of Turin: A Look at the Overall Picture," The Living Church, 182, No. 20, May 17, 1981, pp. 9-11.

Number of Professional Publications, 23; Presentations 8+.
Mailing Address: 15 Tesuque, Los Alamos, New Mexico 87544, USA.
Telephone: Home -- (505) 662-5055; Business -- (505) 667-6804
or (505) 662-5107.

9. THOMAS F. D'Muhala; born 3 April 1940; MS (Nuclear Physics) Massachusetts Institute of Technology; BS University of Connecticut (Physics); Research Experience: Synthesis of uranium monocarbide fuel, single step reducing chemistry nuclear decontamination process for pressurized water reactors, ultrasonic nuclear decontamination. Professional Positions: Nuclear Technology Corporation (President), General Dynamics Corporation (Director of Nuclear Operations), Connecticut Advanced Nuclear Engineering Laboratory of United Technology.

Number of Professional Publications, 50; Presentations 300+.
Mailing Address: P.O. Box 7, Amston, CT 06231, USA.
Telephone: Business -- 537-2387.

10. JAMES ROSS DRUZIK; Professional Positions: Research Laboratory of Los Angeles County Museum of Art, Norton Simon Museum, Pasadena Museum of Modern Art. Specialty: Art Conservation. Professional Societies: International Institute of Conservation; American Institute of Conservation; National Institute of Conservation; Technical Association of the Pulp and Paper Industry; American Chemical Society.

Shroud Publications:

1. Jumper, E. J.; Adler, A. D.; Jackson, J. P.; Pellicori, S. F.; Heller, J. H.; Druzik, J. R., "A Comprehensive Examination of the Various Stains and Images on the Shroud of Turin." Presented at the September 1982 meeting of the American Chemical Society, Kansas City. To be published in ADVANCES IN ARCHEOLOGICAL CHEMISTRY, 1983.

Number of Profession Publications, 5.
Mailing Address: Los Angeles County Museum of Art, 5905 Wilshire Boulevard, Los Angeles, California 90036, USA.

11. WILLIAM R. ERCOLINE; born 26 Oct 1945, MS (Laser-Optics) Air Force Institute of Technology, Ohio; BS (Physics) California State College; Professional Positions: USAF Instrument Flight Center, Air Force Academy (Assistant Professor). Specialty: Physics. Professional Societies: American Association of Physics Teachers; Daedalians.

Shroud Publications:

1. Ercoline, W. R.; Jackson, J. P.; Downs, R., "Examination of the Turin Shroud for Image Distortions," Proceedings of IEEE Conference of Cybernetics and Society, 1982.
2. Jackson, J. P., Jumper, E. J., and Ercoline, W. R., "Three Dimensional Characteristics of the Shroud Image," Proceedings of IEEE Conference on Cybernetics and Society, 1982.

Number of Professional Publications, 4.
Mailing Address: 130 Valencia, Universal City, TX 78148, USA.

12. ROGER GILBERT; PhD (Applied Physics) Queens University, Belfast, 1972; BS (Physics) Queens University, 1969. Research Experience: computer controlled spectroscopy, lasers, spectral absorption of tissue, optical equipment design. Professional Position: Oriel Corporation (President). Specialty: Physics.

Shroud Publication:

1. Gilbert, R., Jr. and Gilbert, Marion, M., "Ultraviolet-Visible Reflectance and Fluorescence Spectra of the Shroud of Turin", Applied Optics, Vol. 19, No. 12, pp. 1930-1936, 15 June 1980.

Mailing Address: Oriel Corporation, 250 Long Beach Blvd, Stratford, CT 06497-0872, USA.

13. GARMAN HARBOTTLE; born 25 Sept 23; PhD, Columbia University, 1949; BS, California Institute of Technology, 1944; Research Experience: radiochemistry, hot atom chemistry of the solid state differential half-life determination, application of nuclear techniques to archaeology and fine arts, techniques in numerical taxonomy, carbon 14. Professional Position: Brookhaven National Laboratory. Specialty: Nuclear Chemistry and Archaeology. Professional Societies: American Chemical Society, Nuclear Section; Society for American Archaeology, Society for Mexican Archaeology, Society for Archaeological Sciences.

Number of Professional Publications, 109.
Mailing Address: Box 2602, Setauket, New York 11733, USA.
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14. JOHN H. HELLER; MD, Case-Western Reserve University; BA, Yale University; Research Experience: Vasoconstriction, renin-hypertensin, reticuloendothelial system, antigen-antibody reactions, bone healing, radio frequency effect, chromosomal aberrations, salmonella typhimurium infection, phagocytosis. Professional Position: New England Institute.

Shroud Publications:

1. Heller, J. and Adler, A., "Blood on the Shroud of Turin," Applied Optics, 19, 1980, p 2742.
2. Heller, J. and Adler, A., "A Chemical Investigation of the Shroud of Turin," J. Can. Soc. Forensic Science, 14, 1981, p 81.
3. Jumper, E. J.; Adler, A. D.; Jackson, J. P.; Pellicori, S. F.; Heller, J. H.; and Druzik, J. R., "A Comprehensive Examination of the Various Stains and Images on the Shroud of Turin," Archaeological Chemistry III, Advances in Chemistry Series of the American Chemical Society, 1984.
4. Heller, J., Report on the Shroud of Turin, Houghton Mifflin Co., Boston, 1983.

Number of Professional Publications, 66.
Mailing Address: 74 Horseshoe Road, Wilton, CT 06897, USA.
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15. JANE K. HUTCHINS, born 20 Mar 53; MS (Textile Materials) North Carolina State University; BA (Art History) Wesleyan University; Research Experience: Conservation, Fabrics, Consulting. Professional Position: Merrimack Valley Textile Museum (Conservator). Specialty: Textile Conservation.

Number of Professional Publications, 6.
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800 Massachusetts, Ave., North Andover, MA 08145.
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16. NOBUKO KAJITANI, born 14 Feb 1935; Research Experience: History of fabrics, Fabric technology, Preservation. Professional Position: Metropolitan Museum of Art (Conservator since 1966). Specialty: Archaeological Textiles. Professional Societies: Fellow of the American Institute of Conservation (AIC), member of International Institute of Conservation (IIC).

Mailing Address: Metropolitan Museum of Art
Department of Textile Conservation
5th Ave. at 82nd St., New York, NY 10028.
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17. KEITH E. PETERSON INMAN; MCrim., Research Experience: Crime scene reconstruction, bloodstain spatter pattern interpretation, field investigations, trace evidence. Professional Position: Forensic Science Services.

Number of Professional Publications, 15.
Mailing Address: Forensic Sciences Services, Town Center, Suite 370,
2501 Cherry Ave., Signal Hill, CA 90806, USA.
Telephone: (213) 424-2220

18. JOHN PHILIP JACKSON; born 2 Feb 1946; PhD (Physics) Naval Postgraduate School, 1972; BS (Physics), Colorado State University, 1967; BA (Religious Studies) College of Santa Fe, 1976; Research Experience: intense laser/solid interactions, infrared detection, microwave interactions, quantum mechanics, physiological parameter modeling; high-energy relativistic proton and electron propagation in air, expanding universe models using Einstein's Field Equations of General Relativity; (1974-Present) Shroud of Turin research. Professional Positions: Kaman Sciences, University of Colorado (Assistant Professor), Air Force Academy (Associate Professor), Air Force Weapons Laboratory. Speciality: Physics. Professional Societies: Sigma Xi; American Institute of Physics; American Institute of Aeronautics and Astronautics..

Shroud Publications:

1. Devan, D.; Jackson, J.; Jumper, E., "Computer Related Investigations of the Holy Shroud". Proceedings of the 1977 United States Conference of Research on the Shroud of Turin.

2. Jackson, J., "Color Analysis of the Turin Shroud: A Preliminary Study". Proceedings of the 1977 United States Conference of Research on the Shroud of Turin.

3. Jackson, J., "A Problem of Resolution Posed by the Existence of a Three-Dimensional Image on the Shroud". Proceedings of the 1977 United States Conference of Research on the Shroud of Turin.

4. Jackson, J.; Jumper, E.; Mottern, W.; Stevenson, K., "The Three-Dimensional Image on Jesus' Burial Cloth". Proceedings of the 1977 United States Conference of Research on the Shroud of Turin.

5. Jackson, J. P. and Jumper, E. J., "Space Science and the Holy Shroud", 1978 II Congresso Internazionale di Sindonologia - La Sindone E La Scienza.

6. Jackson, J. P.; Jumper, E. J.; and Ercoline, W. R., "Correlation of Image Intensity with the Turin Shroud with the 3-D Structure of a Human Body Shape", Applied Optics, Vol. 23, No. 14, pp. 2244-2270, July 15, 1984.

7. Jackson, J. P., "Foldmarks as a Historical Record of the Turin Shroud", Shroud Spectrum International, No. 11, pp. 6-19, June 1984.

8. Jackson, John P. and Jumper, Eric, J., "The Three Dimensional Images on the Holy Shroud", Sindon, October 1977.

9. Jackson, J. P.; Jumper, E. J.; Ercoline, W. R., "Three Dimensional Characteristic of the Shroud Image", IEEE 1982 Proceedings of the International Conference on Cybernetics and Society, #0360-8913/82/0000-0559, pp. 559-575, October 1982.

10. Jumper, E. J.; Adler, A. D.; Jackson, J. P.; Pellicori, S. F.; Heller, J. H.; Druzik, J. R., "A Comprehensive Examination of Various Stains and Images on the Shroud of Turin", ACS Advances in Chemistry, No. 205, Archaeological Chemistry III, Josepeh B. Lambert (Editor), pp. 447-476, 1984.

Number of Professional Publications, 30; Presentations, 300+.
Mailing Address: 747 Tamarron Rd., Colorado Springs, CO 80919, USA.
Telephone: Home -- (303) 594-0741; Business -- (303) 599-1961.

19. RON JENKINS; born 10 Apr 1932; PhD (Chemical Physics), Brooklyn Polytechnic; ONC, HNC, LRIC (Chemistry), Oxford Polytechnic Institute; Research Experience: X-Ray Analytical Methods related to various aspects of materials. Professional Positions: Philips Electronic Instruments, Inc., Application Laboratory in Netherlands (Head). Specialty: Chemical Physics. Professional Societies: Royal Institute of Chemistry; Institute of Physics; Institute of Petroleum; Society for Applied Spectroscopy; Mineralogical Society; Canadian Spectroscopy Society.

Number of Professional Publications, 129.

20. HENRY W. JOHNSON. Professional Position: Los Alamos National Laboratory. Specialty: Photography.

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Telephone: Home -- (505) 662-6830; Business -- (505) 667-1397.

21. R. BARRY JOHNSON; DSc. (Candidate), (Sensor Technology), Southeastern Institute of Technology; MS (Optics), University of Rochester; BS (Physics), Georgia Institute of Technology; Research Experience: Thermal imaging, optics; ultra-sensitive radiographic imaging systems. Professional Positions: Texas Medical Instruments, Inc., Science Applications, Inc. Specialty: Infrared imaging systems. Professional Societies: Optical Society of America; Society of Photo-Optical Instrumentation Engineers.

Mailing Address: Texas Medical Instruments, Inc., One Corporate Drive, Schertz, Texas, 78154, USA.
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22. ERIC J. JUMPER; PhD (Fluid Dynamics/Laser Physics) Air Force Institute of Technology, 1975; MS (Mechanical Engineering) University of Wyoming, 1969; BS (Mechanical Engineering) University of New Mexico, 1968; Research Experience: catalytic chemical reactions, reacting flow, laser fluid and plasma dynamics, human engineering in flight environments. Professional Positions: Air Force Institute of Technology (Associate Professor), Air Force Academy (Associate Professor), Air Force Weapons Laboratory. Specialty: Engineering Physics. Professional Societies: Tau Beta Pi, Sigma Xi, American Institute of Aeronautics and Astronautics.

Shroud Publications:

1. Devan, D.; Jackson, J.; Jumper, E., "Computer Related Investigations of the Holy Shroud". Proceedings of the 1977 United States Conference of Research on the Shroud of Turin.

2. Jackson, J.; Jumper, E.; Mottern, W.; Stevenson, K., "The Three-Dimensional Image on Jesus' Burial Cloth". Proceedings of the 1977 United States Conference of Research on the Shroud of Turin.

3. Jumper, E., "Considerations of Molecular Diffusion and Radiation as an Image Formation Process on the Shroud". Proceedings of the 1977 United States Conference of Research on the Shroud of Turin.

4. Jackson, J. P. and Jumper, E. J., "Space Science and the Holy Shroud". 1978 II Congresso Internazionale di Sindonologia - La Sindone E La Scienza.

5. Jackson, J. P.; Jumper, E. J.; and Ercoline, W. R., "Correlation of Image Intensity with the Turin Shroud with the 3-D Structure of a Human Body Shape", Applied Optics, Vol. 23, No. 14, pp 2244-2270, July 15, 1984.

6. Jackson, John P. and Jumper, Eric, J., "The Three Dimensional Images on the Holy Shroud", Sindon, October 1977.

7. Jackson, J. P.; Jumper, E. J.; Ercoline, W. R., "Three Dimensional Characteristics of the Shroud Image", IEEE 1982 Proceedings of the International Conference on Cybernetics and Society, #0360-8913/82/0000-0559, pp. 559-575, October 1982.

8. Jumper, E. J.; Adler, A. D.; Jackson, J. P.; Pellicori, S. F.; Heller, J. H.; Druzik, J. R., "A Comprehensive Examination of Various Stains and Images on the Shroud of Turin", ACS Advances in Chemistry, No. 205, Archaeological Chemistry III, Joseph B. Lambert (Editor), pp. 447-476, 1984.

9. Jumper E. J., "An Overview of the Testing Performed by the Shroud of Turin Research Project with a Summary of Results", IEEE 1982 Proceedings of the International Conference on Cybernetics and Society", #0360-8913/82/0000-0535, pp. 535-537, October 1982.

10. Jumper, E. J. and Mottern, R. W., "Scientific Investigation of the Shroud of Turin", Applied Optics, Vol. 19, No. 12, pp. 1909-1012, June 15, 1980.

Number of Professional Publications, 42; Presentations, 200+
Mailing Address: 1700 Radcliffe Rd., Dayton, OH 45406, USA.
Telephone: Home -- (513) 274-4807; Business -- (513) 255-2998.

23. J. RONALD LONDON; Specialty: nondestructive testing.

Shroud Publications:

1. Morris, R. A.; Schwalbe, L. A. and London, J. R., "X-Ray Fluorescence Investiation of the Shroud of Turin", X-Ray Spectrometry, Vol. 9, No. 2, pp. 40-47, 1979.

2. Mottern, R. W.; London, R. J.; and Morris, R. A., "Radiographic Examination of the Shroud of Turin - a Preliminary Report", Materials Evaluation, Vol. 38, No. 12, pp. 39-44, 1979.

Mailing Address: Box 3307, Fairview, NM 87533, USA.

24. WILLIAM H. LONG, Jr; MS (Plasma Physics) University of Wisconsin, 1970, BS (Physics) California Institute of Technology, 1969; Research Experience: laser physics, gaseous electronics, molecular kinetics.

Professional Positions: Laser Technology Laboratory Northrop Corporation, Aerospace Research Laboratories. Specialty: Plasma Physics.

25. JEAN J. LORRE; MS (Astronomy and Astrophysics) University of California, Santa Cruz, BA (Physics) California Western University, Sand Diego, 1967; Research Experience: image processing, image understanding, expert systems, SAR image analysis and simulation, spacecraft sensor calibration and decalibration, astronomical applications of image processing, photometric functions, spacecraft navigation, mosaics and map projections. Professional Positions: Research Development Laboratory, Science Applications, Inc., Jet Propulsion Laboratory. Specialty: Physics.

Shroud Publications:

1. C. Avis; D. Lynn; et al, "Image Processing of the Shroud of Turin," IEEE 1982 Proceedings of the International Conference on Cybernetics and Society, 1982, pp. 554-558.
2. J. Lorre and D. Lynn, "Digital Enhancement of Images of the Shroud of Turin," Proceedings on the 1977 U.S. Conference of Research on the Shroud of Turin, Shroud of Turin Research Project, March 1977.

Number of Professional Publications, 35.

26. STEPHEN JOSEPH LUKASIK; born 19 Mar 31; PhD (Physics) Massachusetts Institute of Technology, 1956; MS (Physics) Massachusetts Institute of Technology, 1953; BS (Physics) Rensselaer Polytechnic Institute, 1951; Research Experience: Telecommunications, Xerox copier technology, nuclear detonation detection, fluid physics. Professional Positions: Northrop Corporation (Vice President), Federal Communications Commission (Chief Scientist), Rand Corporation (Chief Scientist), Xerox Corporation, Advanced Research Projects Agency ARPA (Director). Specialty: Physics. Professional Societies: Sigma Xi, American Physical Society, American Association for the Advancement of Science.

Number of Professional Publications, 17+.
Mailing Address: 429 S. Bentley Ave., Los Angeles, CA 90049, USA.
Telephone: Home -- (213) 472-4387; Business -- (213) 377-4811.

27. DONALD J. LYNN; MS (Nuclear Engineering) University of California at Los Angeles; BS (Mechanical Engineering) University of Illinois; Research Experience: remote sensing, image processing on Venus, Mercury, Jupiter and Saturn Space Missions, image processing applied to art conservation and archaeology, electrooptics, the Shroud of Turin, thermal analysis and control, high-performance insulation systems, nuclear propulsion systems. Professional Positions: D. J. Lynn Associates, Jet Propulsion Laboratory, Space Energy Control Systems. Specialty: Image Processing and Information Management.

Shroud Publications:

1. C. Avis; D. Lynn; et al, "Image Processing of the Shroud of Turin," IEEE 1982 Proceedings of the International Conference on Cybernetics and Society, October 1982, pp 554-558.
2. V. Miller and D. Lynn, "Investigation of the Shroud of Turin," Natuur en Technick, (a Dutch Publication), January 1981.
3. J. Lorre and D. Lynn, "Digital Enhancement of Images of the Shroud of Turin," Proceedings of the 1977 U.S. Conference of Research on the Shroud of Turin, Shroud of Turin Research Project, March 1977.

Number of Professional Publications, 21.
Mailing Address: 16660 Ludlow St., Granada Hills, CA 91344.
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28. CATHERINE CLARY McLEAN; born 16 Feb 56; MS (Art Conservation) University of Delaware, 1981; BA (Art History) University of Michigan, 1978; Research Experience: costume and textile conservation, mounting of fragile textiles. Professional Position: Los Angeles County Museum of Art (textile coordinator). Specialty: Art Conservation.

Number of Professional Publications, 4; Presentations, 6.
Mailing Address: 1539 1/2 Silver Lake Blvd, Los Angeles, CA, USA.
Telephone -- Home -- (213) 665-5308.

29. RODERICK J. MCNEAL, born 8 Jan 1949; MS (Biochemistry) South Dakota State University, 1972; BS (Chemistry and Biology) South Dakota State University, 1970; Research Experience: biological life support systems, bioelectrochemical fuel cell development, photosynthesis, portable aviation oxygen systems, vibration-induced osteoarthritis, dating manuscript inks. Professional Positions: Phillips Technologies, Inc. (Director of R&D), Bioenvironmental Research Group, Perkin - Elmer Corporation. Specialty: Biochemistry. Professional Societies: American Society of Experimental Biologists, National Academy of Science, Society of Applied Spectroscopy.

Number of Professional Publications, 16.
Mailing Address: 595 N. Candlewood Lake Road, New Milford, CT 06776, USA.
Telephone: Home -- (203) 354-0427; Business -- (203) 355-3193.

30. VERNON D. MILLER; born 6 May 1932; MS (Education) Pepperdine University, 1974; BA (Photography) Brooks Institute, 1959; Research Experience: scientific and biological photography, forensic photography. Professional Positions: Brooks Institute (Chairman 16 years Industrial/Scientific Department), Aerospace Corporation (8 years staff photographer), Hughes Aircraft (staff photographer). Specialty: Scientific Photography. Professional Societies: International Society of Optical Engineering (SPIE), SPSC, SMPT, and BPA.

Shroud Publications:

1. Miller, V. and Lynn, D., "Delijkwade Van Turijn", Natuur en Techniek, February 1981, pp. 102-125.

2. Miller, V. D. and Pellicori, S. F., "Ultraviolet Fluorescence Photography of the Shroud of Turin", Journal of Biological Photography; Vol. 49, No. 3, pp. 71-85, July 1981.

Number of Professional Publications, 12; Presentations, 100+.
Mailing Address: 438 Loma Alta Drive, Santa Barbara, CA 93109.
Telephone: Home -- (805) 965-5995.

31. J. E. MODISETTE; BS (Engineering Physics) University of Tulsa; Research Experience: infrared imaging, x-ray process control systems, thermal imaging, automotive engineering and testing. Professional Positions: Texas Medical Instruments, Inc. (President), Union Instrument Corporation (President), Automative Research Associates, Inc. (Director R&D). Specialty: Instrumentation and imaging.

Mailing Address: President, Texas Medical Instruments, Inc., One Corporate Drive, Schertz, Texas 78154.
Telephone: Business -- (512) 651-6991.

32. ROBERT W. MOTTERN; BS, East Tennessee University, 1944; Research Experience: nuclear safeguards, nondestructive testing, X-ray. Professional Position: Sandia National Laboratory.

Shroud Publications:
1. Jumper, E. J. and Mottern, R. W., "Scientific Investigation of the Shroud of Turin", Applied Optics, Vol. 19, No. 12, pp. 1909-1912, June 15, 1980.
2. Mottern, R. W.; London, R. J.; and Morris, R. A., "Radiographic Examination of the Shroud of Turin - a Preliminary Report", Materials Evaluation, Vol. 38, No. 12, pp. 39-44, 1979.

Mailing Address: 9006 Lexington Ave, NE, Albuquerque, NM 87112, USA.

33. JACK PEISACH; born 23 Aug 1932; PhD, Columbia University, 1958; MA, Columbia University, 1954; BS, City College of New York, 1953; Research Experience: biochemistry, pharmacology, molecular biology, biophysics. Specialty: Biochemistry. Professional Position: Albert Einstein College of Medicine (Professor). Professional Societies: American Chemical Society, Biophysical Society, American Society of Biological Chemists, New York Academy of Sciences, American Society for Pharamacology and Experimental Therapeutics.

Number of Professional Publications, 170.

34. SAMUEL F. PELLICORI; MS (Optical Sciences), University of Arizona; BS (Physics), University of Arizona. Research Experience: ultraviolet, visible, infrared materials and filters optical properties and applications; polarimetric, photometric and spectrometric instrumentation, spectroradiometry, thin film interference coating design and deposition. Professional Position: Santa Barbara Research Center. Specialty: Optics. Professional Societies: Optical Society

of America, SPIE, Sigma Xi Scientific Research Society, Society of Applied Spectroscopy.

Shroud Publications:

1. S. Pellicori, "Optical Properties of the Shroud of Turin," Applied Optics, 19, 1980, p 1913.
2. S. Pellicori and Mark Evans, "The Shroud of Turin Through the Microscope," Archaeology, 34, 1981, p 34.
3. S. Pellicori and R. A. Chandos, "Portable Unit Permits UV/VIS Study of 'Shroud'," Ind. Res. and Devel., 23, 1981, p 186.
4. S. Pellicori and V. D. Miller, "Ultraviolet Fluorescence Photography of the Shroud of Turin," J. Biological Photographers Assoc, 49, No. 3, 1981, p 71.
5. S. Pellicori; E. J. Jumper; A. D. Adler; J. P. Jackson; J. H. Heller; and J. R. Druzik, "A Comprehensive Examination of the Various Strains and Images on the Shroud of Turin," Archaeolgical Chemistry III, Advances in Chemistry Series of the American Chemical Society, 1983.
6. Pellicori, S. F., "Spectrochemical Results of the 1978 Investigation", Sindon, 1981.

Number of Professional Publications, 28.
Mailing Address: Santa Barbara Research Center, Bldg 3, M/S 54, Goleta, CA 93117, USA.
Telephone: Business -- (805) 968-3571 (ext. 2379).

35. GIOVANNI RIGGI; Research experience: scientific instrumentation, biology, zoology, botany, microbiology, x-ray fluorescence analysis, particle analysis. Professional Position: S.P.R. Co. Torino (Director). Specialty: Microanalysis.

Shroud Publication:

1. Riggi, G., Rapporto Sindone, Torino, 1980.

Mailing Address: Via G. Giacosa, 21 bis 10125 Toroni, Italia
Telephone: 6506834 (Turin, Italy)

36. PETER M. SCHUMACHER; born 31 July 45; Specialty: Electronic remote sensing and image processing, design engineer for VP-8 image analyzer. Professional Societies: Society of Photo-Optical Instrumentation Engineers, American Congress on Surveying and Mapping, Armed Forces Communication and Electronics Association, American Radio Relay League. Specialty: Image Processing. Professional Positions: Measuronics Corporation (Vice President), Interpretation Systems, Inc., Nihon Dengyo Company Limited (Japan).

Number of Professional Publications, 1.
Mailing Address: 41 Devonshire, Great Falls, Montana 59401, USA.
Telephone: (406) 727-7459.

37. LARRY ALLEN SCHWALBE; PhD (Physics) University of Illinois, 1973; MS (Physics) University of Illinois, 1969; BS (Engineering Physics) University of Illinois, 1968; Research Experience: thermodynamic properties of molecular gas solids, diamond-anvil cells, x-ray fluorescence analysis, image and signal processing in nondestructive testing. Professional Positions: Los Alamos National Laboratory, Technical University in Munich, Germany (post Doc.). Specialty: Physics.

Shroud Publications:

1. Morris, R. A.; Schwable, L. A.; London, J. R., "X-ray Fluorescence Investigation of the Shroud of Turin," X-ray Spectrom, 9, 1980, pp 40-47.
2. Schwalbe, L. A., and Rogers, R. M., "Physics and Chemistry of the Shroud of Turin: A Summary of the 1978 Investigation," Anal. Chim. Acta 135, 1982, pp 3-49.

Number of Professional Publications, 15.
Mailing Address: 253 Canada Way, Los Alamos, NM 87544, USA.
Telephone: Home -- (505) 672-9184; Business -- (505) 667-2421.

38. RONALD M. SEGA; born 4 Dec 1952; Ph.D. (Electrical Engineering) University of Colorado, 1982; MS (Physics) Ohio State University, 1975; BS (Math and Physics) United States Air Force Academy, 1974; Research Experience: Applied Electromagnetic Field Theory, Infrared Detection of Microwave Induced Surface Currents, Electromagnetic Compatibility Studies, Scanning Electron Microscopy, Atomic Physics, Laser Damage, Photovoltaic Solar Cells, and Radiation Effects on Materials. Positions: University of Colorado (Assistant Professor), Air Force Academy (Assistant Professor). Specialty: Applied Infrared/Microwave Physics. Professional Societies: American Physical Society, Institute of Electrical and Electronic Engineering, International Society of Optical Engineering (SPIE).

Number of Professional Publications, 24; Presentations, 17.
Mailing Address: Department of Electrical Engineering
University of Colorado
Colorado Springs, CO 80933, USA.
Telephone: Home -- (303) 593-9315; Business -- (303) 593-3510.

39. EDDY A. STAPPAERTS; PhD (Lasers and Nonlinear Optics) Stanford University, 1976; MS (System Theory) Stanford University, 1972; Research Experience: nonlinear optics, optical pulse compression, ultra-short pulse generation, IR Countermeasures, IR imaging, electrical discharge lasers, alkali metal vapors, multiphoton pumped rare-gas excimers, two-photon transitions. Professional Position: Quantum Electronics Laboratory at Northrop Corporation (Manager). Specialty: Physics. Professional Societies: Optical Society of America, IEEE.
Number of Professional Publications, 30.

APPENDIX D

LIST OF QUESTIONS AND WORK PACKAGES PROPOSED TO ADDRESS THEM

The following list of questions illustrates the scope of the proposed studies. The appropriate work package(s) which addresses these questions appears in brackets. It will be noted that many questions are addressed by different work packages; this illustrates the inherent multidisciplinary character of the proposed examination. The questions are arranged to roughly correspond with increasing work package number as given in the proposal text. At the beginning of each question is a code which shows the relationship of the question to Conservation-C, Authenticity-A, and Image Formation-I. Of the 85 questions, 32(38%) have conservation implications, 39(46%) authenticity, and 51(60%) image formation. It is likely that additional questions which can be addressed by the data will become apparent after the proposed examination is conducted.

1. AI Has the body image always been visible or did it develop with time against a slower developing cloth background? [1]

2. CAI What is the discoloration (degradation) rate of the Shroud cellulose as a function of temperature, oxygen availability, and UV radiation flux? [1,5]

3. CA What was the relative effect of the 1532 fire with respect to natural aging discolorations? [1]

4. CA What further discoloration (degradation) effects can be expected on the Shroud? [1]

5. AI In what temporal order did the blood and body images physically appear on the Shroud? [2]

6. CAI Are blood images human blood? [3,10,21]

7. AI Are there materials present on the Shroud that can further confirm the forensic hypothesis that the cloth covered a wounded human body? [3,10]

8. I Can any of the various proposed image hypothesis mechanisms (e.g. scorch, ionization, photolytic, chemical, etc.) be tested? [1,3]

9. AI Are there artist's materials present on the Shroud and can they be accounted for? [3]

10. AI Can novel materials be discovered that in themselves suggest new ideas concerning the nature of the Turin Shroud? [3,10]

11. C What is the pH of the Shroud and how does it affect aging of the Shroud? [4]

AC What is the fiber content of the Shroud (e.g. linen, cotton, etc.)? [4]

C What is the tensile strength of the Shroud threads? [4]

C What effect do the old mends, patches, have on the state of the Shroud? [4]

C What effect do the charred regions have on catalyzing further cellulose degradation? [4]

C How adequate are the current storage conditions for the Shroud? [4,11]

C What are the effects of humidity on the Shroud? [4]

C What are the degradation effects in the waterstain regions? [4,15,25]

C What are the effects of Turin's Urban/Industrial air pollution environment upon the Shroud and image? [4,5]

C What are the effects of inorganic elements, known since 1978 to exist on the Shroud, upon the degradation rate of the Shroud cloth? [5,23,24,25]

CA How old is the Shroud? [1,5,6]

I Can previous image analysis studies pertaining to image resolution, enhancement, and three-dimensional interpretation be improved? [8]

CI What is the penetration depth of the body image into the cloth? [8,18]

I What is the relative reflectance of the dorsal to the frontal body image (at presumed contact points)? [8,23]

I Does the shading structure of the dorsal body image permit a three-dimensional interpretation as does the frontal image? [8]

A What is the nature of the features in the eye region which have been suggested to be Pilate Lepton coin inscriptions? [8]

I What are the spatial limits of the detectable body image? [8,21]

A Are there any subtle discoloration features which might be associated with historical display or storage configurations (e.g. an oval around the face as suggested in the Mandylion hypotheses)? [8]

29. A Are there foldmarks on the Shroud which are consistent with its being once folded as the Mandylion? [8,9,20]

30. A What folding patterns can be seen on the Shroud? [9]

31. CAI Does the body image contain any dried pigmentation which might produce a detectable irregularity in the random crease and wrinkle structure of the Shroud? [9]

32. C What are the effects of creases on the integrity of the blood images? [9]

33. C What is (are) the cause(s) of the wrinkle structures on the Shroud? [9]

34. AI From a forensic point of view, what is the probable sequence of events which lead to the image structures (i.e. body and blood) on the Shroud? [10]

35. I What is the thermal diffusivity of the Shroud both longitudinally and transversely? [11]

36. C What is the temperature distribution of the Shroud while it is stored and being unrolled? [11]

37. I Can spectral data in the infrared be obtained which provides chemical information concerning the image? [11,23]

38. I What does the entire Shroud look like in the infrared while being illuminated with visible light? [11]

39. A Is the hypothesis that the image is that of Jesus consistent with what is observed on the Shroud? [10,6,12]

40. A In what climate was the flax for the Shroud grown (i.e. Europe or Middle East)? (12]

41. CAI Can microbiological activity explain the presence of iron oxide on the Shroud and/or the coloring of the bloodstains? (15]

42. C Are there any conservation issues regarding possible microbiological degradation of the Shroud? [15]

43. C What varieties of dusts (including pollens) and small animalicula exist on the Shroud? [16]

44. C Can the Shroud image be restored by computer analysis to the original state? [19]

5. AI Can the weave structure be eliminated from the eye region in such a way as to not disturb the image (possibly that of a coin) in that area? [19]

6. AI Can the inorganic pigment hypotheses (e.g. Fe_2O_3) be quantitatively tested by x-radiography, more sensitive than in 1978? [20]

7. A What is the structure of the seam joining the alleged "side strip" to the Shroud? [20]

8. A Does the side strip represent a separate piece of material sewn onto the Shroud or a continuation of the Shroud with a seam being an added artifact? [20]

9. A What is the three-dimensional structure of various foldmarks found on the Shroud? [9,20]

0. CA What is the structure of the edges of the Shroud? [20]

1. AI What does the "serum"/blood interface look like? [21,8]

2. CAI Where are particles (dust) found? [21]

3. I Can particulate material be seen in the water front zones? [21]

4. AI Can more detail in the skin wounds, eyes, etc. be observed? [21,8]

5. AI Can greater detail in the body-only image be observed? [21,8]

6. AI Can blood density variation, serum, and water front zones be documented? [21,8]

7. AI What do body, scorch, cloth, blood, waterstain fibrils look like at high magnifications? [21]

8. I What are the visible fluorescent characteristics of various areas on the Shroud (e.g. body, blood, waterstain, cloth, scorch, etc.)? [21]

9. I How does the "serum"/blood transition zone fluoresce visibly? [21]

0. I Can differences between scorch and body image be recorded for later quantification and comparison with photoelectric spectrometry? [2,8]

1. I Do water front zones show different fluorescence? [21]

2. I What is the fluorescent pattern of the cloth weave? [21]

63. I Is the Shroud body image the result of a thermal scorch? [22]

64. I Why are there color differences among and within blood stain regions? [23]

65. I What is the spectrum of the skin wound stains? Is it like blood? [23]

66. I Based on different blood spectra - can age, chemistry, microbiology, exposure, etc., account for the spectral features? [23,14,3]

67. AI How do the spectra of bloodstains compare with those of various pigments that have been suggested (Fe_2O_3,HgS, etc.)? [23]

68. I Are there detectable differences in spectral absorption (or reflectivity) of widely separated or specific body image areas? [23]

69. I Quantitatively, can subtle differences between scorch and body image be defined? [23]

70. C How do chemical/physical environments - past, present, and future - influence the spectra of the body image? [23]

71. C What predictions can be made from the spectra relative to conservation issues? [23]

72. C Can we obtain absolute spectra on defined areas to serve as reference data to track temporal degradation effects in the future? [1,23]

73. C What are the microscopic effects of stress on the Shroud material, particularly on the foldmarks? [24,9]

74. I Are there differences in the degree of cellulose crystallinity on either side of the "chin band" image discontinuity that might correlate with the discontinuous shading in this region? [24]

75. AI Are there pigments in the blood regions? [3,24,25,26]

76. I Are there variations in elemental concentrations in the "chin band" area which might correlate with the discontinuous image shading in this region? [25]

77. AI Is there a correlation between image shading and iron (or other inorganic) concentration in the body image? [25,26]

78. AI Is there mercuric sulfide in the bloodstain regions? [3,25]

). I What is the elemental composition of the body image areas compared with background areas, including the side of the cloth? [25,26]

). AI What is the elemental composition of the scourge-mark areas compared with blood, halo, body-image, and background areas? [26]

1. CAI What is the elemental composition of the area between the dorsal hips compared with blood, halo, and body image areas? Is there feces contamination there? [3,26]

2. I What is the elemental composition of the finger areas compared with that of body-image and background areas? [26]

3. AI Do the shoulder and calves (leg) areas of the Shroud contain deposits of dirt or dust similar to the heel area? [26]

4. I What is the variation, if any, of the elemental composition of the background? [26]

5. C Is sodium chloride responsible for helping to preserve the Shroud from deterioration? [26]

APPENDIX E

TENTATIVE SCHEDULE FOR PERFORMING PROPOSED TESTS

The following table illustrates how the proposed STURP testing program might be performed during the requested three week examination. This is not meant to necessarily be a definitive time-table, but to give some idea as to the arrangement format involved in executing the examinations in as minimum a time frame as possible. This necessitates twenty-four hour, round the clock examination. We note that such a procedure was successfully executed by STURP in 1978 during its five day examination period.

The requested time of three weeks is longer than the examination period of 1978, but is shorter than the total display plus examination time of seven weeks in 1978. It is conceivable that the examinations could be performed in a shorter time period, but, as obvious from the table, this would necessitate more than one examination being performed at any given time. This presents complications which we believe are unwise from the standpoints of optimal scientific study and safety of the Shroud.

The schedule given below is arranged so that research personnel can follow a reasonably normal work schedule. Each work package is given the time period as specified in each work package. The only exceptions are work packages #1, 3, and 7 which will be operative concurrently with some of the other proposed studies (i.e. beyond that scheduled in this table). Between most work blocks are one hour time intervals which allow for an orderly transition between examination teams and equipment. The Day and hour numbers are indices denoting the clock time for the testing in which Day 1, hour 1 is the starting time of the proposed examination (e.g. Wednesday at 0800). The numbers in the table indicate the corresponding work package and the X's denote requested discretionary time to allow flexibility in the testing program (e.g. for examinations which might have had unanticipated problems during the allocated time blocks or to follow up on unexpected observations). We note that, in 1978, STURP's program was planned for only four days but was allowed one extra day of discretionary time. We further note that in 1978 the schedule was adjusted to accommodate other research teams; a similar procedure could be followed here.

Finally, if it is possible to remove the backing cloth from the Shroud as requested in some work packages, we suggest that it be done one week prior to the start of the prepared examination, with hours 1-10 on day 1 being performed prior to the removal in that case.

Day →	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Hour ↓																					
1	11	4	3		1		17	13	4	11			23		24	X	X	25	25	25	25
2	11	4	3	1	1	23				11	19	20	23	2	24	X	X	25	25	25	25
3	11	4	3	1	1	23	15	7	23	11	19	20		2	24	X	X	25	25	25	25
4	11	4		1	1		15	7	23		19	20	10	2	24	X	X	25	25	25	25
5	11	4	10	1	1	10	15	7	23	6	19	20	10	2		X	X	25	25	25	25
6	11	4	10		1	10	15	7	23	6	19	20		2	21	19	X	25	25	25	25
7			10	13	7	10	15	7	23	6	19	20	22	2	21	19	X	25	25	25	25
8	9	13	10	13	7	10			23	6			22		21	19	X	25	25	25	25
9	9	13	10	13	7		18	10	23	6	23	8		18	21	19	X	25	25	25	25
10	9	13	10	13	3	9	18	10	23	6	23	8	21	18	21	19	X	25	25	25	25
11		13		13	3	9	18	10	23		23	8	21	18	21	19	X	25	25	25	25
12	14	13	18	13	3	9	18	10	23	8	23	8	21	18		X	X	25	25	25	25
13	14	13	18	13	3	9	18			8	23	8	21	18	16	X	X	26	26	26	26
14		13	18		3	9	18	8	13	8	23		21	18	16	X	X	26	26	26	26
15	3	13	18	3		9		8	13	8	23	23	21		16	X	X	26	26	26	26
16	3	3	18	3	9	9	20	8	13	8	23	23	21	20		X	X	26	26	26	26
17	3	3	18	3	9	9	20	8	13			23	21	20	8	X	X	26	26	26	26
18	3	3		3	9	9	20	8	13	10	13	23		20	8		X	26	26	26	26
19	3	3	7	3	3	9	20		13	10	13	23	16	20	8	21	X	26	26	26	26
20	3	3	7	3	3		20	4	13	10	13	23	16	20	8	21	X	26	26	26	26
21	3	3	7	3	3	17	20	4		10	5	23	16	20	8	21	X	26	26	26	26
22	3	3	7	3	3	17		4	11		5	23	16			21	X	26	26	26	26
23	3	3	7	3	3	17	13	4	11	12	5	23	16	24	X	21	X	26	26	26	26
24		3	7			17	13	4	11	12	5	23	16	24	X	21	X	26	26	26	26

APPENDIX F

SAMPLES REQUESTED TO BE REMOVED FROM SHROUD

Some of the work packages require samples to be removed from the Shroud in order to extract the desired information. So as to provide proper and convenient documentation of the sample requirements of the STURP proposal, we provide here a review of those requirements.

There are three categories of samples requested:

1. Microscopic - These are fibrils (of threads), particles, dusts, pollens, etc. which, when removed, do not affect the appearance of the Shroud to the naked eye owing to their smallness.

2. Macroscopic (removed) - These are areas of cloth or threads which, when removed, leave a scar large enough to be visible to the naked eye. This category can be further subdivided into those samples which come from the Shroud proper and those which come from non-Shroud materials.

3. Macroscopic (non-removed) - These are areas of the Shroud which are properly considered as samples but are not removed from the Shroud since the studies are able to be performed in place.

LIST OF SAMPLES

In 1978, only category 1 samples were removed by STURP. Category 2 samples were removed from the Shroud by the 1969/1973 Commission and non-STURP examination personnel in 1978. Category 3 samples, to our knowledge, have never been part of Shroud tests.

The list of samples by category and appropriate work package (in brackets) is as follows:

1. Microscopic (fibrils and particles) [2,3,10,14,15,16,17,24,25,26].

2. Macroscopic (removed)
   a. Shroud cloth
      (1.)* 1 cm^2 (15 mg) [5]
      (2.) 200 mg (approximately 10 cm^2 or square 3.2 cm on a side) from side strip [6]
      (3.) 200 mg (approximately 10 cm^2 or square 3.2 cm on a side) from lower right hand corner [6]
      (4.)** 200 mg (approximately 10 cm^2 or square 3.2 cm on a side) charred material under each patch [6]for a total of 10x16 = 160 cm^2 or 3.2 g.
      (5.) 60 mg (approximately 3 cm^2 or square 1.7 cm on a side) from edge of Shroud [12]

(6.)*** 2 non-image threads (1-3 cm long) from fold area [24]
(7.)*** 2 non-image threads (1-3 cm long) from non-fold area [24]
(8.)*** 2 threads or 120 μg particles from bloodstain [24]
(9.)*** 20 non-image threads (1 cm long) [4, see ref. 10]

b. Non-Shroud cloth
(1.) 200 mg (approximately 10 cm^2 or square 3.2 cm on a side) from a patch [6]
(2.) 200 mg (approximately 10 cm^2 or square 3.2 cm on a side) from Holland backing cloth [6]

3. Macroscopic (non-removed)
a.*** 9 one-centimeter diameter penetrating discolorations of low reflectivity (twice that of the body image) [1]
b.*** 10 one-centimeter size nonpenetrating scorches on reverse side of Shroud [22]

In addition, it is requested that the Holland backing cloth be separated from the Shroud in places [10,13,16,18,25,26] and completely [8,13,18,20] (if possible) for rear surface examination of the Shroud. The cloths could be reattached after the examination (in 1978, permission was given for detachment of Shroud from the backing cloth by King Umberto's representative, but STURP elected not to perform this procedure).

NOTES:

* This sample will not be taken if Work Package #1 is successful.

** This material when removed will present no visible artifact since it comes from beneath the patches.

*** If possible, these samples (removed and non-removed) might be able to be taken from beneath the blue border fabric, thereby presenting no visible artifact. However, this would have to be evaluated on-site.

APPENDIX G

RESOURCES GENERATED BY PROPOSED EXAMINATIONS

The resources that would result from the proposed investigation ar as follows (relevant work packages indicated in brackets):

1. Conservation assessment and recommendations [4,5].
2. Color photographs with better detail than in 1978 [13].
3. Video documentation with audio of entire examination and discussio sessions [13].
4. Color transmission photography of bloodstains [19].
5. Set of high quality x-radiographs [20].
6. Set of special photographs, more extensive and specific than in 197 [21].
7. Set of UV fluorescence photographs [21].
8. Set of Reflected UV photographs [21].
9. Baseline spectral measurements which can serve as standards for futur generations to assess image degradation [23].
10. Substantial data base which will characterize Shroud for furthe analyses and for future generations.