SMITHSONIAN INSTITUTION

CONSERVATION ANALYTICAL LABORATORY

MUSEUM SUPPORT CENTER

Washington, D.C. 20560

February 9, 1996

Mr. Mark Gilberg
National Center for Preservation Technology and Training
Northwestern State University
Box 5682
Natchitoches, LA 71497

Dear Mark,

As you requested we am sending a letter as a final report for the research grant "The Development of General Guidelines for Setting Safe Allowable Temperature Fluctuations for Museums, Historic Sites, and Cultural Collections," for the fiscal year 1995.

Summary of Basic Concepts.

In order to be able to develop safe ranges of temperature variation for both cultural materials and objects constructed from them, certain requirements needed to be met and considerable information determined. These included: determining accurate mechanical and thermal properties of polymeric materials; determining their failure mechanisms; relating thermal behavior to the mechanical and thermal properties of materials; establishing a mechanical property criterion for setting thermal limits; developing an understanding of the worst case structural conditions that would most likely be found in objects constructed of multiple materials, and developing analytical models to assess the behavior of temperature on the objects constructed of multiple materials.

The Grant itself required that we make the critical connection between the mechanical properties of materials and their thermal behavior. Further, it was necessary to start an active dissemination of the information through published papers, conferences and seminars. I think it is reasonable to say that we accomplished this and more.

It is worth expanding a bit on all of the points mentioned above and finally discussing their implications and approaches to using the information.

1. The Mechanical Properties of Materials.

To date we have measured the mechanical properties of dozens of cultural materials. The materials include both new and old woods, a wide variety of paints, modern adhesives and traditional glues, parchments, papers, photographic emulsions and bases, hides, and other materials. These measurements included determining the yield points (the strains at which the materials make the transition from elastic behavior to plastic behavior), the ultimate strength (the stress at which the material breaks), and the stiffness of the materials (the modulus). These measurements were conducted under a wide variety of temperatures, relative humidities and rates of applied loads. The yield points were particularly necessary since these strain values were used as one of the criteria for setting the thermal limits.

2. The Thermal Behavior of Cultural Materials.

The primary measurements needed for the thermal properties were the dimensional response to thermal change and the glass transition temperature, T_g. The dimensional properties were needed to develop the relationship between the thermal and mechanical behavior of the materials. The glass transition temperatures were needed since they were used as a secondary thermal limit criteria. Above the glass transition temperature, materials responding to thermal change can be considered subjected to fairly slow load application and as such exhibit considerable ductile behavior. That is to say, there is often a significant plastic response to loading prior to breaking. Below the glass transition temperatures, materials become extremely brittle and glassy in their mechanical behavior. In many cases, the strains reached at the failure of the material are less than the yield strains and hence, set the low temperature limit of the material.

3. Relating the Thermal Behavior to the Mechanical Properties of the Materials.

This was the primary task of the research grant for without this work thermal limits could not be established with any confidence. Basically this work shows that the free swelling thermal strains exhibited by any material are in fact identical to the mechanical strains developed in a material when it is restrained and either heated or cooled. This is the worst case condition when stresses develop in the materials. Since this is the shown to be the case, then the strain caused by thermal change can be directly related to the strains occurring either at yielding (above T_g) or at or below T_g. We have enclosed a very recently published paper (ICCI '96 Conference sponsored by the NSF and the University of Arizona) that discusses this work and relates it to the effects of relative humidity.

4. Establishing a Mechanical Property Criterion for Setting the Safe Allowable Thermal Ranges.

In all of the materials tested, the yield point not only represents the transition from the elastic behavior (dimensionally reversible) to the plastic behavior (permanent deformation occurs), but cyclic testing in the elastic region (strains to yield) has to date demonstrated no evidence that fatigue damage is occurring in the materials in these strain ranges. The cyclic tests have been over 5000 cycles at 1.5 Hertz to full yield strains. These cyclic tests include woods, paints, glues, etc. This represents over 100 years of 50 annual full thermal or RH swings in the allowable range. For example, for a traditional oil paint, the RH swings could have been from 20% RH to 80% RH or the thermal swings could have been from -10° C to 35° C even if the paint had been fully restrained from any movement at all. For a wood restrained in the tangential direction (the worst case), the RH range could have been 35% RH to 65% RH, but the temperature range may be much larger than that of the oil paint. The low temperature limit for the oil paint is the glass transition temperature assuming that the paint had been completely restrained from any movement at room temperature.

This information is detailed in the enclosed manuscript, "Technical Considerations for the Transport of Panel Paintings," by M. Richard, M. Mecklenburg, and C. Tumosa. This paper is in press for the upcoming book of the proceedings of the Getty Conference on the Structural Restoration of Panel Paintings, held in 1995.

The research has shown that for nearly all materials, the yield point is initially reached when the strain is 0.004. The exception to this has been brittle gesso which has demonstrated a yield of 0.0025. This includes both tension and compression. In addition, it has been found that nearly all of the materials have demonstrated strain hardening which means that after being strained to levels beyond the yield point, the elastic region increases beyond strains of 0.004. Other exceptions to this are materials tested below the glass transition temperature. These can actually break before yield is reached, thus the needed caution in loading material at these low temperatures.

5. Developing Worst Case Structural Conditions

Those materials that are fully restrained during environmental changes such as fluctuations in temperature or relative humidity would certainly constitute the vast majority of worst case situations. For example, paint on wood when examined in the direction parallel to the grain is restrained since the wood moves very little in that direction. Another case is the layer of veneer applied in a manner such that its grain is perpendicular to the base wood grain.

Other conditions that increase the stress levels are existing cracks in materials. This is particularly true when the temperatures are near or below the glass transition temperatures of the materials. Most of the organic cultural materials exhibit ductility above T_g when developing environmental induced stresses. This is a moderately slow process and crack tips tend to be blunted, thereby reducing stress concentration. Below T_g, materials tend to exhibit little if any ductility and crack tips tend to remain sharp with associated high stress concentrations.

6. Developing Analytical Models to Assess the Behavior of Composite Objects (Constructed of Multiple Materials).

We had already developed numerical models such as Finite Element Analysis (FEA) for complex structures on the computer . What has been developed recently is the closed form model that is very simple to use and is extremely useful for that very large body of structures where thin coatings or materials are applied to much heavier substrates. This can included any painted surface, photographic materials, veneers and laminated systems, and others. This method is illustrated in the paper, "Technical Considerations for the Transport of Panel Paintings."

7. Implementing the Information.

In general, determining the environmental fluctuations (temperature or relative humidity) for a class of museum objects is not all that difficult now. If an accurate description of the dimensional response of materials to changes in temperature and relative humidity are available, then it becomes simply finding what change in temperature (or relative humidity) causes a change in strain of ± 0.004. It is important to keep in mind that expansion coefficients are rarely constants even though they are nearly always published as such. These values are always approximations and are not accurate enough for our purposes. In the case of temperature drops it is useful to know the glass transition temperatures for materials. For example, traditional oil paints have a T_g of around -10° C to -15° C, Alkyd paints have a T_g around -5° C and acrylic paints have a T_g between +5° C and +10° C (note these are not very low temperatures). We have long suspected that severe temperature drops were responsible for much of the damage attributed to relative humidity. This has now been confirmed. It is our intention to finish an investigation of the materials and publish a fairly comprehensive compendium of the materials information that has and will be accumulated.

Budget Status

As I have discussed with you we have used almost none of the funds provided for this project. There are two basic reasons for this. First, we had provided a job description for the technician to be hired under the grant within the first four weeks to the Smithsonian Institution Personnel Office. It took them three months to get out the announcement and the applicants were all unsuitable. We re-advertized the job and again there were no suitable candidates. At this point, we were nine months into the contract. Second, during the early period of the contract, a major program "Art in Transit, 3D Objects'" which required a considerable amount of our time, was discontinued due to reasons known only to the director of CAL. We found the we could divert much of our time and resources to the contract.

As a consequence we have discussed an alternative program use for the funds. This includes three international three day conferences in 1997, In Washington, Germany and The Netherlands. The subject matter of these conferences will be the mechanics and structure of cultural materials and objects and their response to temperature and relative humidity. In addition, we are preparing a manuscript which will result in a major monograph that will be made available at the time of the conferences and the National Gallery of Art has agreed to bear the cost of publishing the book. This program will be detailed in a separate proposal which we will send you in the very near future.

Dissemination of the Research Results

We are enclosing copies of articles to which we refer in this letter and other materials that are either directly related to or a consequence of the research we have done under this contract. In addition we have presented the research information and its implications at the following conferences.

* Richard, M., M. F. Mecklenburg, and C. S. Tumosa, "Technical Considerations for the Transport of Panel Paintings," Paper presented at the Symposium on the Structural Conservation of Panel Paintings, 1995.

* A four part presentation on the on the current research on the effects of temperature and relative humidity on the structural integrity of museum objects and its implications on the museum environment was made at the request the Conservation Center at New York University. This presentation was on June 35, 1995 at NYU. Participating in the presentation was MFM, CST, WDE, and MMcG. There were additional speakers including Don Sebera, Jim Reilly, Stefan Michalski, Bill Lull, and Jim Drusik. This conference was called to discuss the new approach to controlling the museum environment. (you were at this conference.)

* Invited Speaker at the "Cursos de Verano de la Universidad Complutense" Held at the Escorial, Madrid, Spain July 10-14, 1995. This week long course was titled, "Museums After the Year 2000." Other speakers included the directors of the major museums in Europe and the heads of conservation for the Louvre and the

National Gallery of Art. The presentation M. F. Mecklenburg gave was in the technical section and prompted considerable interest and has lead to an invitation to develop a three day conference jointly with the State Gallery of Modern Art, in Munich.

* A detailed presentation on the effects of environment on museum objects at NASM and the allowable variation they could sustain was presented by MFM, CST and MMcCG at NASM on January 3, 1995. Martin Harwit and his staff were present along with engineers from HOK, OPlants, etc.

* A second 2 and a half hour technical presentation on the effects of environment and its implications to museums was made at the request of ODC and OPLANTS. Doug Wonderlic, with representatives from those offices and the NMAI and Guggenheim Museum. This presentation was on February 13, 1995 by MFM, CST, WDE, and MMcG.

* A 3 hour presentation on the on the current research on the effects of temperature and relative humidity on the structural integrity of museum objects and its implications on the museum environment was made at the request the SI Conservation Consortium. This presentation was on July 25, 1995 at the Carmichael Auditorium at the National Museum of American History. Participating in the presentation was MFM, CST, WDE, and MMcG.

* Presented a poster with C. S. Tumosa, "Structural Stability of the Collections and Museum Energy Costs," at the Increase dialogue symposium at the National Zoo, March, 1995.

If you have any questions feel free to contact either of us at your convenience. We look forward to your input.

Best regards,

Marion F. Mecklenburg, Ph.D.　　Charles S. Tumosa, Ph.D.

cc: Karen Otiji, Office of Sponsored Projects, SI.