Chapter 4: Museum Collections Environment

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CHAPTER 4: MUSEUM COLLECTIONS ENVIRONMENT

A. Overview

1. *What information will I find in this chapter?*

This chapter will give you information on how to protect your collection from deterioration caused by interaction with the surrounding environment. From the moment an object is created, it begins to deteriorate. The factors that can cause deterioration are called "agents of deterioration." See Chapter 3 for a more complete discussion of the agents of deterioration.

This chapter will address four agents that can be grouped under the term **environment**:

- temperature
- relative humidity
- light
- air pollution

Understanding how the environment affects your collection and how to monitor and control these agents of deterioration is the most important part of a preventive conservation program.

In order to understand how the agents of deterioration react with the objects in your collection, you must develop a "critical eye." This skill allows you to identify active deterioration and its causes. How you do this is described below.

2. *Who should read this chapter?*

You should read this chapter if you are responsible for the care of the museum collections. Use this chapter to develop an understanding of how objects deteriorate. This chapter will help you develop environmental monitoring programs so you can identify and block these agents of deterioration before they can damage your collections or so you can mitigate the damage that has been caused. Every park should have an environmental monitoring program.

3. *What are the agents of deterioration that affect the museum environment?*

The agents of deterioration are forces that act upon objects causing chemical and physical damage.

- **Contaminants** disintegrate, discolor or corrode all types of objects, especially reactive and porous materials. Contaminants include:
  - *gases* (pollutants such as hydrogen sulfide, nitrogen dioxide, sulfur dioxide and ozone; oxygen)
  - *liquids* (plasticizers that ooze from adhesives, grease from human hands)
  - *solids* (dust that can abrade surfaces, salt that corrodes metals)

- Air pollution can include all these types of contaminants.

- Radiation can be:
  - *ultraviolet* radiation that disintegrates, fades, darkens, and/or yellows the outer layer of organic materials and some colored inorganic materials
  - *unnecessary visible light* that fades or darkens the outer layer of paints and wood

- Incorrect temperature can be:
  - *too high* causing gradual disintegration or discoloration of organic materials
  - *too low* causing desiccation, which results in fractures of paints, adhesives, and other polymers
  - *fluctuating* causing fractures and delamination in brittle, solid materials

- Incorrect relative humidity can be:
  - *damp (over 65% RH)* causing mold and corrosion
  - *above or below a critical value* hydrating/dehydrating some minerals
  - *above 0%* supports hydrolysis that gradually disintegrates and discolors organic materials, especially materials that are chemically unstable
  - *fluctuating,* which shrinks and swells unconstrained organic materials, crushes or fractures constrained organic materials, causes layered organic materials to delaminate and/or buckle, loosens joints in organic components.

This chapter discusses protection from incorrect temperature, incorrect relative humidity, light (electromagnetic radiation), and pollutants. Other chapters cover the other agents of deterioration. Direct physical forces are discussed in Chapter 7: Handling, Packing and Shipping. Thieves, vandals, and fire are discussed in Chapter 9: Security and Fire Protection. Pests are described in Chapter 5: Biological Infestations. Water and many of the other agents are discussed in Chapter 10: Emergency Operation Plans.

There are a variety of ways you can protect your collections from the agents of deterioration. There are four steps to stop or minimize damage:

- **Avoid the agents of deterioration.** For example, choose a site for your collection storage that is away from the flood plain of a river or stream. Build a storage facility that is properly insulated and does not have windows in collections areas.

- **Block the agents when you cannot avoid them.** This is probably the main way most museums protect their collections in historic buildings. For example, if your collection storage area has windows, cover them with plywood. Place UV filters on fluorescent lights to block damaging radiation. Fill cracks and gaps in a building structure to limit entry to pests.

- **Test the methods you use to block agents of deterioration by monitoring**. For example, set up an Integrated Pest Management (IPM) program to find out if you have pests. Monitor relative humidity and temperature to find out if your HVAC system is working properly.

- **Respond to information you gather with your monitoring programs.** Monitoring is a waste of time if you do not review, interpret, and use the information. This chapter will tell you how to monitor temperature and relative humidity, light, and air pollution and how to respond to the data that you collect.

Only if these first four approaches fail should you have to recover from deterioration. Recovery usually means treating an object. While a treated object may *look* the same, once damage has occurred, an object will never *be* the same. Your aim in caring for your collection should be to carry out preventive tasks so that treatment is not needed.

Many objects will come to your museum collections damaged and deteriorated from use and exposure. Because of their history, even in the best museum environment, some objects will need treatment. You should develop a treatment plan for immediate problems in the collection. Your primary goal, however, is to create a facility that will minimize damage and maintain the collection through preventive measures.

B. Developing the Critical Eye

1. *What is the "critical eye?"*

The "critical eye" is a way of looking at objects to evaluate their condition and identify reasons for changes in the condition. You develop this skill over a period of time through both training and experience. You must continually ask yourself the questions:

- What is occurring?
- Why is it occurring?
- What does it mean?

The critical eye is a trained eye.

Your trained eyes will focus on the materials and structure of the object and look for visual clues to the agents of deterioration in the environment. A person with a trained eye readily recognizes danger signs, records them and associates them with the condition of the museum collections, and implements actions to slow down or stop deterioration. Examples of problems that you will see with a trained eye include:

- sunlight falling on a light sensitive surface
- condensation forming on cold surfaces
- water stains appearing on ceilings or walls
- insect residues and mouse droppings

You must learn about the following topics to develop your critical eye:

- types of materials that make up a museum collection
- inherent characteristics of objects
- types of deterioration

The success of a preventive conservation program relies on the gathering, recording, and evaluating of all this information in order to implement solutions and to mitigate environmental factors that are harmful to a park's museum collection.

2. *What kinds of materials will I find in a museum collection?*

Museum objects are often divided into three material-type categories: organic, inorganic, and composite. You must understand the properties of each of the materials in each of these categories.

Organic Objects: Organic objects are derived from things that were once living — plants or animals. Materials are processed in a multitude of ways to produce the objects that come into your collections. Various material types include wood, paper, textiles, leather and skins, horn, bone and ivory, grasses and bark, lacquers and waxes, plastics, some pigments, shell, and biological natural history specimens.

All organic materials share some common characteristics. They:

- contain the element carbon
- are combustible
- are made of complicated molecular structures that are susceptible to deterioration from extremes and changes in relative humidity and temperature
- absorb water from and emit water to the surrounding air in an ongoing attempt to reach an equilibrium (hygroscopic)
- are sensitive to light
- are a source of food for mold, insects, and vermin

Inorganic Objects: Inorganic objects have a geological origin. Just like organic objects, the materials are processed in a variety of ways to produce objects found in your collections. Material types include: metals, ceramics, glass, stone, minerals, and some pigments.

All inorganic objects share some common characteristics. They:

- have undergone extreme pressure or heat
- are usually not combustible at normal temperature
- can react with the environment to change their chemical structure (for example, corrosion or dissolution of constituents)
- may be porous (ceramics and stone) and will absorb contaminants (for example, water, salts, pollution, and acids)
- are not sensitive to light, except for certain types of glass and pigments

Composite Objects: Composite or mixed media objects are made up of two or more materials. For example, a painting may be made of a wood frame and stretcher, a canvas support, a variety of pigments of organic and inorganic origin, and a coating over the paint. A book is composed of several materials such as paper, ink, leather, thread, and glue. Depending on their materials, composite objects may have characteristics of both organic and inorganic objects. The individual materials in the object will react with the environment in different ways. Also, different materials may react in opposition to each other, setting up physical stress and causing chemical interactions that cause deterioration.

3. *What is deterioration?*

Deterioration is any physical or chemical change in the condition of an object. Deterioration is inevitable. It is a natural process by which an object reaches a state of physical and chemical equilibrium with its immediate environment.

The types of deterioration can be divided into two broad categories: physical deterioration and chemical deterioration. Both types often occur simultaneously.

4. *What is chemical deterioration?*

Chemical deterioration is any change in an object that involves an alteration of its chemical composition. It is a change at the atomic and molecular level. Chemical change usually occurs because of reaction with another chemical substance (pollution, water, pest waste) or radiation (light and heat). Examples of chemical change include:

- oxidation of metals (rusting)
- corrosion of metals and stone caused by air pollution
- damage to pigments by air pollution or reaction with other pigments
- staining of paper documents by adjacent acidic materials

- fading of dyes and pigments
- darkening of resins
- darkening and embrittlement of pulp papers
- burning or scorching of material in a fire
- embrittlement of textile fibers
- bleaching of many organic materials
- cross-linking (development of additional chemical bonds) of plastics
- rotting of wood by growing fungus

5. *What is physical deterioration?*

Physical deterioration is a change in the physical structure of an object. It is any change in an object that does not involve a change in the chemical composition. Physical deterioration is often caused by variation in improper levels of temperature and relative humidity or interaction with some mechanical force. Examples of physical deterioration include:

- melting or softening of plastics, waxes, and resins caused by high temperature
- cracking or buckling of wood caused by fluctuations in relative humidity
- warping of organic materials caused by high relative humidity
- warping or checking of organic materials caused by low relative humidity
- shattering, cracking, or chipping caused by impact
- crushing or distortion caused by a harder material pressing against flexible material
- abrasion caused by a harder material rubbing against a softer material
- structural failure (for example, metal fatigue, tears in paper, rips in textiles)
- loss of organic material due to feeding by insects and/or their larvae
- staining of textiles and paper by mold

Physical deterioration and chemical deterioration are interrelated. For example, chemical changes in textiles caused by interaction with light also weaken the fabric so that physical damage such as rips and tears may occur.

6. *What is inherent vice?*

In addition to deterioration caused by the agents of deterioration, certain types of objects will deteriorate because of their internal characteristics. This mechanism of deterioration is often called ***inherent vice*** or ***inherent fault***. It occurs either because of the incompatibility of different materials or because of poor quality or unstable materials.

In nature, materials often possess characteristics that protect them from natural degradation. Their structure and composition may include features such as protective layers, insect and mold resistant chemicals, and photochemical protection. Processing during object manufacture can remove these natural safeguards. Additives may be applied to give a desired result, without concern for long-term preservation (for example, the addition of metal oxides in the manufacture of weighted silk). This processing results in inherently less stable materials or combinations of mutually incompatible substances that have damaging interaction. There are three kinds of inherent vice:

Short-lived materials: Short-lived materials are often the result of manufacturing processes that do not consider the long-term stability of the items that were produced. Many objects now in park museum collections originally were made to fulfill temporary needs. Examples of impermanent materials with inherent vice include:

- cellulose nitrate and cellulose ester film
- wood pulp paper
- many 20th century plastics
- magnetic media, including electronic records

Structural nature: Inherent vice can also be related to the structure of an object. Poor design, poor construction, or poor application of materials may cause structural failure. Examples of such damage include:

- drying cracks in paint improperly applied
- broken or lost attachments
- loose joints

History: The way an object was used or where it was stored or deposited before it comes into your collection may lead to inherent vice. Here, damage and deterioration is caused by the original function of the object, its maintenance, or its environment. Examples of inherent vice caused by history include:

- accumulation of dissimilar paint layers, such as oil and latex
- saturation in a wooden bowl that had been used as a container for oil
- deposits of soluble salts in an archeological ceramic during burial

You may have trouble identifying deterioration caused by inherent vice because often there is little or no information on the selection and processing of materials, manufacturing details, and previous use of an object. Train your critical eye by reviewing similar objects and by developing knowledge of object technology. Over time, you will become more proficient at identifying inherent vice.

7. *Why is it important to understand the environmental agents of deterioration and how to monitor them?*

If you understand basic information about the chemistry and physics of temperature, relative humidity, light, and pollution, you will be better able to interpret how they are affecting your museum collections. This chapter gives you a basic overview of these agents and describes how to monitor them. You will be able to tell how good or bad the conditions in your museum are and whether or not the decisions you make to improve the environment are working the way you expect.

The rest of this chapter gives you guidelines for deciding on the best environment that you can provide for your collections. However, because of the huge variation in materials found in collections and the extremes in geography where NPS collections are stored, no strict standards can be set. In the past, simplified standards such as 50% RH and 65°F were promoted. With research and experience, it is now understood that different materials require different environments. You must understand the needs of your collection for the long-term in order to make thoughtful decisions about proper care.

You will want to develop microenvironments for storage of particularly fragile objects. A microenvironment (microclimate) is a smaller area (box, cabinet, or separate room) where temperature and/or humidity are controlled to a different level than the general storage area. Common microenvironments include:

- freezer storage for cellulose nitrate film
- dry environments for archeological metals
- humidity-buffered exhibit cases for fragile organic materials
- temperature-controlled vaults for manuscript collections

C. Temperature

1. *What is temperature?*

Temperature is a measure of the motion of molecules in a material. Molecules are the basic building blocks of everything. When the temperature increases, molecules in an object move faster and spread out; the material then expands. When the temperature decreases, molecules slow down and come closer together; materials then contract. Temperature and temperature variations can directly affect the preservation of park collections in several ways.

2. *How does temperature affect museum collections?*

Temperature affects museum collections in a variety of ways.

- At higher temperatures, chemical reactions increase. For example, high temperature leads to the increased deterioration of cellulose nitrate film. If this deterioration is not detected, it can lead to a fire. As a rule of thumb, most chemical reactions double in rate with each increase of 10°C (18°F).

- Biological activity also increases at warmer temperatures. Insects will eat more and breed faster, and mold will grow faster within certain temperature ranges.
- At high temperatures materials can soften. Wax may sag or collect dust more easily on soft surfaces, adhesives can fail, lacquers and magnetic tape may become sticky.

In exhibit, storage and research spaces, where comfort of people is a factor, the recommended temperature level is 18-20° C (64-68° F). Temperature should not exceed 24° C (75° F). Try to keep temperatures as level as possible.

In areas where comfort of people is not a concern, temperature can be kept at much lower levels—but above freezing.

Avoid abrupt changes in temperature. It is often quick variations that cause more problems than the specific level. Fluctuating temperatures can cause materials to expand and contract rapidly, setting up destructive stresses in the object. If objects are stored outside, repeated freezing and thawing can cause damage.

Temperature is also a primary factor in determining relative humidity levels. When temperature varies, RH will vary. This is discussed in more detail in the next section.

D. Relative Humidity

1. *What is relative humidity (RH)?*

Relative humidity is a relationship between the volume of air and the amount of water vapor it holds at a given temperature. Relative humidity is important because water plays a role in various chemical and physical forms of deterioration. There are many sources for excess water in a museum: exterior humidity levels, rain, nearby bodies of water, wet ground, broken gutters, leaking pipes, moisture in walls, human respiration and perspiration, wet mopping, flooding, and cycles of condensation and evaporation.

All organic materials and some inorganic materials absorb and give off water depending on the relative humidity of the surrounding air. Metal objects will corrode faster at higher relative humidity. Pests are more active at higher relative humidities.

We use relative humidity to describe how saturated the air is with water vapor. "50% RH" means that the air being measured has 50% of the total amount of water vapor it could hold at a specific temperature. **It is important to understand that the temperature of the air determines how much moisture the air can hold.** Warmer air can hold more water vapor. This is because an increase in the temperature causes the air molecules to move faster and spread out, creating space for more water molecules. For example, warm air at 25°C (77°F) can hold a maximum of about 24 grams/cubic meter (g/m^3), whereas cooler air at 10°C (50°F) can hold only about 9 g/m^3.

Relative humidity is directly related to temperature. In a closed volume of air (such as a storage cabinet or exhibit case) where the amount of moisture is constant, a rise in temperature results in a decrease in relative humidity and a drop in temperature results in an increase in relative humidity. For example, turning up the heat when you come into work in the morning will decrease the RH; turning it down at night will increase the RH.

Relative humidity is* inversely *related to temperature. In a closed system, when the temperature goes up, the RH goes down; when temperature goes down, the RH goes up.

2. *What is the psychrometric chart?*

The relationships between relative humidity, temperature, and other factors such as absolute humidity and dew point can be graphically displayed on a **psychrometric chart**. Refer to Figure 4.1 for an explanation of how to use this chart. The following definitions will help you understand the factors displayed on the chart and how they affect the environment in your museum.

- **Absolute humidity** (AH) is the quantity of moisture present in a given volume of air. It is not temperature dependent. It can be expressed as grams of water per cubic meter of air (g/m^3). A cubic meter of air in a storage case might hold 10 g of water. The AH would be 10 g/m^3.

- **Dew point** (or saturation temperature) is the temperature at which the water vapor present saturates the air. If the temperature is lowered the water will begin to condense forming dew. In a building, the water vapor may condense on colder surfaces in a room, for example, walls or window panes. If a shipping crate is allowed to stand outside on a hot day, the air inside the box will heat up, and water will and condense on the cooler objects.

- **Relative humidity** relates the moisture content of the air you are measuring (AH) to the amount of water vapor the air could hold at saturation at a certain temperature. Relative humidity is expressed as a percentage at a certain temperature. This can be expressed as the equation:

$$RH = \frac{\text{Absolute Humidity of Sampled Air x 100}}{\text{Absolute Humidity of Saturated Air at Same Temperature}}$$

Use the following example to understand how this concept relates to your museum environment.

In many buildings it is common to turn the temperature down in the evenings when people are not present. If you do this in your storage space, you will be causing daily swings in the RH. Suppose you keep the air at 20°C (68°F) while people are working in the building. A cubic meter of air in a closed space at 20°C (68°F) can hold a maximum of 17 grams of water vapor. If there are only 8.5 grams of water in this air, you can calculate the relative humidity.

The AH of the air = 8.5 grams
The AH of saturated air at 20°C = 17.0 grams
Using the equation above

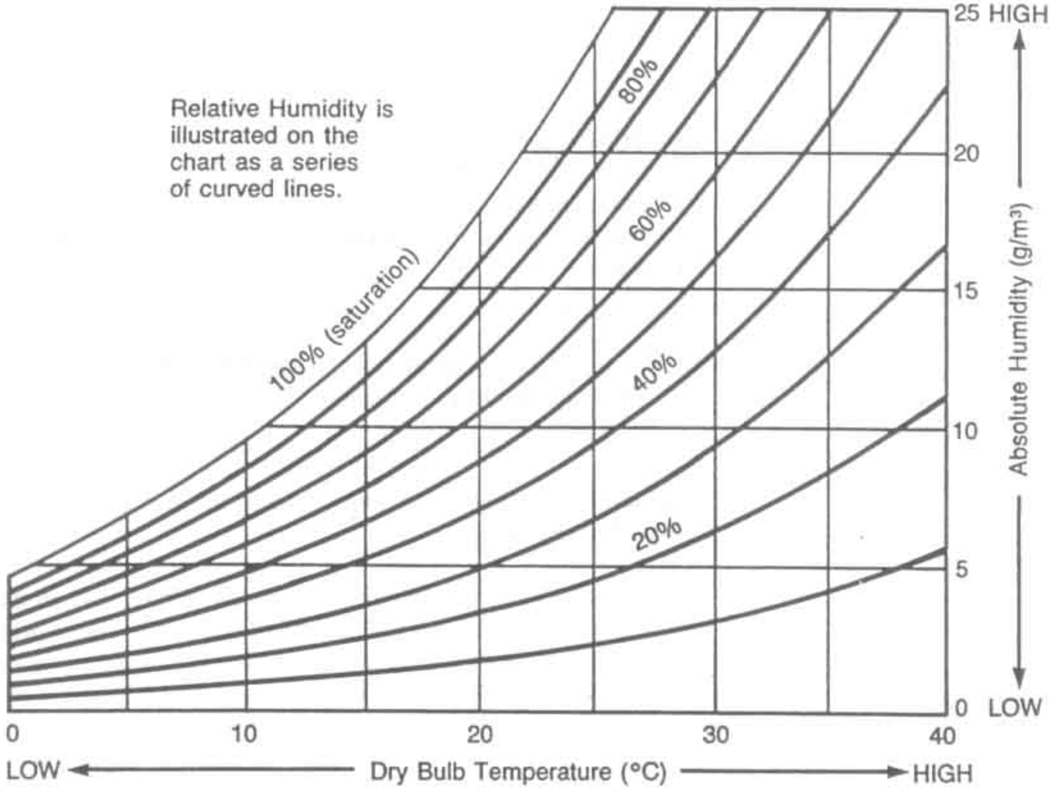
$$RH = \frac{8.5 \text{ x } 100\%}{17.0} = 50\%$$

50% RH may be a reasonable RH for your storage areas. But, if you turn down the heat when you leave the building at night, the RH of the air in the building will rise rapidly. You can figure out how much by using the same equation. If the temperature is decreased to 15°C (59°F), the same cubic meter of air can hold only about 13 grams of water vapor. Using the same equation

The AH of the air = 8.5 grams
The AH of saturated air at 15°C (59°F) = 13.0 grams

$$RH = \frac{8.5 \text{ x } 100\%}{13.0} = 65\%$$

By turning down the heat each night and turning it up in the morning you will cause a 15% daily rise and fall in RH.



Follow any horizontal line (representing a specific amount of moisture in the air) from left to right on the chart (i.e., from lower to higher temperature levels). Note that RH decreases as temperature increases, so long as the quantity of moisture in the air does not change.

Again, follow any horizontal line, but this time from right to left (i.e., from higher to lower temperatures). Note that RH levels increase, although the amount of moisture in the air remains constant. Finally, 100% RH is reached at the left edge of the chart, when the temperature drops to the dew point. The air is now saturated and will have to give up water (e.g., as condensation) at any lower temperature.

Note that moving from left to right on the chart along the upward curving RH lines corresponds to increasing amounts of moisture in the air. This shows that maintaining a constant level of relative humidity, as the temperature rises, requires adding moisture to the air. Conversely, if the temperature falls, the downward sloping RH lines indicate that water has to be removed from the air to maintain RH at a constant level.

Turning down the heat to increase the RH may be beneficial to a museum collection if the RH is too low. On the other hand, turning down the heat in relatively damp conditions may increase the RH to the level where mold grows, or even to the dew point where condensation may harm vulnerable surfaces.

Figure 4.1. How to Use a Psychrometric Chart

3. *How do organic objects react with relative humidity?*

Organic materials are ***hygroscopic***. Hygroscopic materials absorb and release moisture to the air. The RH of the surrounding air determines the amount of water in organic materials. When RH increases they absorb more water; when it decreases they release moisture to reach an equilibrium with the surrounding environment. The amount of moisture in a material at a certain RH is called the ***Equilibrium Moisture Content*** (EMC). Refer to Appendix N: Curatorial Care of Wooden Objects, for a further explanation of this concept. Over time, these reactions with water can cause deterioration.

4. *What deterioration is caused by relative humidity?*

Deterioration can occur when RH is too high, variable, or too low.

- **Too high:** When relative humidity is high, chemical reactions may increase, just as when temperature is elevated. Many chemical reactions require water; if there is lots of it available, then chemical deterioration can proceed more quickly. Examples include metal corrosion or fading of dyes. High RH levels cause swelling and warping of wood and ivory. High RH can make adhesives or sizing softer or sticky. Paper may cockle, or buckle; stretched canvas paintings may become too slack. High humidity also supports biological activity. Mold growth is more likely as RH rises above 65%. Insect activity may increase.

- **Too low:** Very low RH levels cause shrinkage, warping, and cracking of wood and ivory; shrinkage, stiffening, cracking, and flaking of photographic emulsions and leather; desiccation of paper and adhesives; and dessication of basketry fibers.

- **Variable:** Changes in the surrounding RH can affect the water content of objects, which can result in dimensional changes in hygroscopic materials. They swell or contract, constantly adjusting to the environment until the rate or magnitude of change is too great and deterioration occurs. Deterioration may occur in imperceptible increments, and therefore go unnoticed for a long time (for example, cracking paint layers). The damage may also occur suddenly (for example, cracking of wood). Materials particularly at high risk due to fluctuations are laminate and composite materials such as photographs, magnetic media, veneered furniture, paintings, and other similar objects.

5. *What are the recommendations for relative humidity control?*

You should **monitor** relative humidity and implement improvements to stabilize the environment. There are many ways to limit fluctuations, not all dependent on having an expensive mechanical system. For example, good control is achievable simply by using well-designed and well-constructed storage and exhibit cases.

Ideally, fluctuations should not exceed ±5% from a set point, each month. You should decide on a set point based on an evaluation of your particular regional environment. Consult your regional/SO curator, a conservator or other expert in museum environments. Establish maximum and minimum levels by assessing the nature and condition of the materials in the collection and the space where they are housed. Establishing ranges is discussed in more detail in Section B. For example, if you are in Ohio you may decide on a set point of 50%±5%. The humidity could go as high as

55% or as low as 45% within a month. If you are in the arid southwest you might choose 35% as your set point as objects have equilibrated at much lower RH levels. Be aware though, you should not allow your RH to go as high as 65% because of the chance that mold might develop. Below 30% some objects may become stiff and brittle.

Over the year you may want to allow ***drift.*** Drift means that your set point varies in different seasons—usually higher RH in the summer and lower RH in the winter. Allowing drift will often save you money over the long-term as mechanical systems work less to maintain the proper environment. If your collections are housed in a historic structure, preservation of the structure may require drift. It is important to understand that these variations in RH and temperature should be slow and gradual variations (over weeks and months), not brief and variable.

Archeological Materials	
Negligible Climate-Sensitive Materials	30% – 65%
Climate Sensitive Materials	30% - 55%
Significantly Climate Sensitive Materials	30% - 40%
Metals	<35%
Natural History Materials	
Biological specimens	40% - 60%
Bone and teeth	45% - 60%
Paleontological specimens	45% - 55%
Pyrite specimens	<30%
Paintings	40% - 65%
Paper	45% - 55%
Photographs/Film/Negatives	30% - 40%
Other organics (wood, leather, textiles, ivory)	45% - 60%
Metals	<35%
Ceramics, glass, stone	40% - 60%

Figure 4.2. Relative Humidity Optimum Ranges for Various Materials Housed in a Park's Museum Collection.[1]

E. Monitoring and Controlling Temperature and Relative Humidity

1. *Why should I monitor temperature and relative humidity?*

You must monitor temperature and relative humidity so that you know what the environment in your storage and exhibit spaces is like over time. Monitoring helps you:

- set a baseline of temperature and humidity to see if the storage space is adequate
- identify variations in the temperature and humidity throughout collections areas

- monitor equipment to be sure it is working right
- help develop strategies to improve the environment
- identify whether your strategies are working to improve the environment

2. *What kind of monitoring equipment should I have?*

There are a variety of temperature and relative humidity monitoring tools that are available for monitoring the environment in your museum. They can be divided into two types: spot measuring devices and continuous recording devices. Each type is most effective for different specific tasks so you may need to purchase more than one of the following pieces of equipment:

- **Psychrometers:** All parks should have a psychrometer. There are two types: **sling psychrometer** and **aspirating psychrometer.** Of the two, an aspirating psychrometer is more accurate. You use a psychrometer to record daily readings (if you don't have a hygrothermograph), to make spot readings, and to calibrate dial hygrometers and hygrothermographs. See *Conserve O Gram* 3/1, "Using a Psychrometer To Measure Relative Humidity."

  A psychrometer gives you the RH by comparing the temperature between a "dry bulb" and "wet bulb." The dry bulb is a mercury thermometer. The wet bulb is an identical thermometer covered with a wetted cotton wick. Because of the cooling effect of evaporating water, the wet bulb reads lower than the dry bulb. The drier the air, the faster the water evaporates and the lower the reading.

  To take readings with a sling psychrometer, whirl it around for one minute to pass air over the wet and dry bulbs. Read the wet bulb immediately and record the results. Repeat the process until you get the same readings two times in a row.

  The aspirating psychrometer uses a battery powered fan to steadily blow air over the bulb at a set speed. Both these instruments are accurate to ±5%. The aspirating psychrometer is more reliable because it minimizes possible errors by the operator and ensures a constant air flow past the wick. Accuracy will also depend on the length of the thermometer and how accurately you can read the temperature.

  Before you use a psychrometer, be sure to read the manufacturer's instructions. To ensure you get an accurate reading keep the following points in mind:

  – keep wick closely fitted to the thermometer bulb

  – do not touch the wick

  – keep the wick clean

  – use only deionized water to wet the wick

  – be sure that the aspirating psychrometer has a good battery

Accuracy of aspirating and sling psychrometers can be affected by altitude, especially at lower relative humidities. At lower atmospheric pressure water evaporates faster, lowering the temperature of the dry bulb more. If your collections are 900 meters or more above sea level, you should obtain pressure-corrected charts, tables, or slide rules or use a pressure correction formula. See the article by Hitchcock and Jacoby (listed in the bibliography) for more information about the effects of high altitude on psychrometers, and indirectly on the equipment that you calibrate using a psychrometer.

- **Hygrometers:** You can use a hygrometer to measure relative humidity levels when you don't have a hygrothermograph or datalogger or in spaces that are too small for psychrometers (for example, inside an exhibit or a storage case). When you use a hygrometer, also record the temperature. There are three types of hygrometers: dial hygrometers, electronic hygrometers, and humidity strips.

  In a **dial hygrometer,** a hygroscopic material (often paper) is attached to a hand on a dial. As the hygroscopic material absorbs or gives off moisture, it expands and contracts, causing the hand to move across the dial. Dial hygrometers can be accurate to ±5%, but they are very inaccurate at low (<40%) and high (>80%) RH levels. Often they are hard to calibrate, so over time will drift and become inaccurate. See *Conserve O Gram* 3/2, "Calibration of Hygrometers and Hygrothermographs."

  Digital hygrometers often have a built-in temperature monitor. If you purchase one of these tools be sure it can be calibrated. They are often calibrated with saturated salt solutions provided in a kit by the manufacturer. Electronic hygrometers can be used to calibrate hygrothermographs if you are sure the hygrometer is in proper calibration.

  Humidity indicator strips are a special kind of hygrometer that use paper impregnated with cobalt salts. A series of patches are labeled with RH, usually in 10% increments. The color is blue at low RH levels and pink at high RH levels. Read the RH at the point of change between pink and blue. These strips are inexpensive and can give you some basic understanding of your RH levels at a variety of spots around your building. If used in a moist environment, they can become inaccurate.

- **Hygrothermographs:** Hygrothermographs have been the basic monitoring tool in museums for some time. They give you a continuous record of temperature and humidity variations over a period of 1, 7, 31, or 62 days. The instrument consists of six major components:

  – the housing

  – a temperature element, usually a bimetal strip

  – a relative humidity element, which may be a human hair bundle or a polymer membrane

- linkage arms and recording pens
- a drive mechanism, which may be spring wound or battery operated, that rotates a chart
- a chart, which may be wrapped around a cylindrical drum or be a circular disk

The temperature-sensitive element (the bimetal strip) and the hygroscopic material (for example, the human hair) are connected to arms with pens at their tips. The pens rest on a revolving chart and move up and down as the bimetal strip and the hair react to environmental changes.

Hygrothermographs are accurate within ±3-5% when properly calibrated. They are most accurate within the range of 30-60% RH. **Note:** You must calibrate your hygrothermograph at least quarterly; monthly is better. It is especially important to calibrate your machine if you experience sudden extremes of humidity in your collection areas. See *Conserve O Gram* 3/2, "Calibration of Hygrometers and Hygrothermographs."

- **Electronic datalogger:** Electronic dataloggers have become common in museums. There are a variety of types of dataloggers available at a range of prices. A model that records temperature, relative humidity, and light will meet typical museum needs. The data must be downloaded onto a computer. All datalogger companies provide at least basic software programs that allow you to manipulate the data to produce graphs and tables of information. Most allow you to transfer this information in ASCII format to a spreadsheet program. They require less calibration than hygrothermographs, though they must usually be sent back to the company for calibration.

  Many dataloggers do not display data so you will not have any indication of what is occurring in your environment until you download the data. Some now include a liquid crystal display unit. See *Conserve O Gram* 3/3, "Datalogger Applications in Monitoring the Museum Environment" for a discussion of your options when choosing a datalogger. See *Conserve O Gram* 14/6, "Caring for Color Photographs," for information about using the Preservation Environment Monitor (PEM). The PEM is a datalogger that automatically figures the time-weighted preservation index (TWPI). The TWPI is an estimate of how long organic objects will last at a given temperature and RH. See Section F.10 for a further explanation of the TWPI.

  Electronic dataloggers can be very useful instruments, but they are not exact replacements for hygrothermographs. Before purchasing all new equipment evaluate what information you need from your continuous monitoring equipment, consider these questions:

  - How much can you spend?
  - How many areas do you need to monitor?

- Do you need a portable monitor or will it remain in the same place all the time?

- Do you have the computer equipment and knowledge to properly use dataloggers?

- How much time do you have available for changing charts, downloading data, calibrating instruments, and manipulating data.

- How much data manipulation do you require? Can you just review charts or do you want do be able to look at and produce graphs that reflect daily, monthly, and yearly trends?

- Do you need immediate notification of the environment in an area so you can respond to changes?

- Information regarding some kinds of environmental equipment is published in the NPS *Tools of the Trade*. It is important to evaluate equipment available through a variety of other companies, as well. Electronic hygrometers and dataloggers are changing constantly and you should make yourself aware of new options before making your final choice.

3. *How do I maintain a hygrothermograph?*

In order to get the best information possible from your hygrothermograph, you must maintain and calibrate it on a regular basis. Make it a standard maintenance chore that you do at the same time each quarter, or preferably once a month when you change the recording paper.

Before using your instrument, read the manufacturer's instruction for operation and maintenance. Hygrothermographs are delicate instruments and you can easily damage yours by improper handling. See *Conserve O Gram* 3/2, "Calibration of Hygrometers and Hygrothermographs." Keep the following points in mind when changing the paper and calibrating:

- Keep the instrument clean and free of dust.

- Locate the instrument in an area that minimizes vibration, but reflects the environment throughout the room.

- Do not touch the relative humidity sensor.

- Replace the relative humidity sensor when you find you are frequently adjusting the RH calibration.

- Keep the pens clean and free flowing.

- If you have metal tipped pens, use only the glycerine based ink supplied with your instrument. Other types of ink will not work. You can also get felt-tip cartridge pens, which are are easier to use. However, these pens have a shorter shelf life. If properly maintained, the metal pen points with ink are more cost effective.

When you calibrate your hygrothermograph, you will check the instrument against known relative humidity and/or temperature levels and make adjustments as necessary. **Note:** Temperature rarely goes out of calibration because the bimetal element is very stable. Use either a sling psychrometer or an aspirating psychrometer to determine the relative humidity. See *Conserve O Gram* 3/1, "Using a Psychrometer to Measure Relative Humidity." Next adjust the hygrothermograph to match the known conditions. Use the example chart in Figure 4.3, Hygrothermograph Calibration Record, to document the calibration.

Do the calibration:

- Read and follow any suggestions made by the manufacturer concerning calibration of the instrument.

- Record the information requested on the chart: date, time of day, relative humidity reading from the hygrothermograph, and temperature reading from the hygrothermograph.

- Immediately after recording readings obtained from the hygrothermograph, operate the psychrometer **at the same location,** following the manufacturer's instructions. Record the relative humidity and dry bulb temperature readings on the psychrometer in the spaces provided on the record.

- Adjust the hygrothermograph to match the psychrometer readings. Follow the instructions for making adjustments provided by the instrument's manufacturer. If the average differences are found to be greater than 1% relative humidity or 1° in temperature, adjust the hygrothermograph up or down to match the calibrating instrument reading. For example, if the hygrothermograph is recording high by 5%, adjust the recording arm so that it shows the proper reading. If the hygrothermograph is recording temperature low by 4º, adjust the recording arm to the actual reading.

- If the hygrothermograph requires calibration, record the temperature and humidity difference in the appropriate spaces. For example, if the relative humidity reading on the hygrothermograph was 48% and the reading from the psychrometer was 45%, record the difference between them as "hygro high by 3% RH." **Always record differences in terms of whether the hygrothermograph reading is higher or lower than the psychrometer reading** because you are calibrating the hygrothermograph. If there is no difference between the two readings, simply enter "0 difference" in the space.

- Wait for 15 minutes and take another psychrometer reading. Check the reading on the hygrothermograph again. You may need to adjust the instrument because the linkages often require time to equalize.

- If significant differences still exist (over 5%) after a third check, refer to the instruction manual for the hygrothermograph to determine why the instrument might be malfunctioning. Relative humidity readings most often are erroneous because of a broken or dirty hair element. Temperature readings can be in error because of dust or other fouling of the bimetal strip. **Read and follow the manufacturer's**

instructions for cleaning, maintaining, and repairing the hygrothermograph.

After the calibration has been completed and the hygrothermograph has been adjusted properly, file the calibration record form with the charts from the hygrothermograph. It is important that the forms be kept so that they can be compared to future calibration records on the same instrument in order to determine if there is a pattern of incorrect readings. If it becomes apparent that a hygrothermograph has consistently given incorrect readings, return it to the manufacturer for repairs.

NATIONAL PARK SERVICE
HYGROTHERMOGRAPH CALIBRATION RECORD

Hygrothermograph: **Brand** *Weathermeasure* **Model** *5020-A*
Serial No. *008581* **Property No**. *NP0000105512*

Psychrometer: **Brand** *Cole-Parmer Thermo-hygrometer* **Model** *3309-60*
Serial No. *942803* **Property No.** *NP0000105409*

Location of Hygrothermograph: *Museum Storage, top of Cabinet 3A*

Name and Title of Person: *Rhonda Fleming, Curator*

		Relative Humidity Readings			Temperature Readings		
DATE	TIME	HYGRO.	PSYCH.	±RH DIFF.	HYGRO.	PSYCH.	±° DIFF.
4/11/99	***1300***	***55%***	***54%***	***+1%***	***65°F***	***65°F***	***0°F***
5/11/99	***800***	***53%***	***54%***	***-1%***	***65°F***	***65°F***	***0°F***
6/10/99	***1400***	***55%***	***55%***	***0%***	***65°F***	***62°F***	***+3°F***

Figure 4.3. Example Hygrothermograph Calibration Record

4. *How do I read a hygrothermograph chart or datalogger graph?*

If you have spent any time inspecting hygrothermograph charts or datalogger graphs you may have observed readings that defy simple explanations. There are many variables that may account for unusual readings. Some of them include:

- the quality and condition of the building where your collection is housed (the "envelope")
- staff activity
- public visitation
- HVAC equipment performance and failure
- barometric pressure
- weather
- the condition and accuracy of the monitoring equipment
- an unusual source for moisture such as curing concrete, underground cisterns, clogged drains

It is impossible to explain all of the patterns you may encounter in a monitoring program. However, some common patterns and causes can be explained:

- Examine the hygrothermograph chart in Figure 4.4. This pattern clearly illustrates the relationship between temperature and relative humidity. As the temperature goes down, the RH goes up. As the temperature goes up, the RH goes down. You may see this pattern most often in well-enclosed spaces with minimal human activity (for example, a storage space). A large number of people gathering in a room would probably cause an increase in both temperature (because of body heat) and relative humidity (because of perspiration and transpiration).

- Examine the hygrothermograph chart in Figure 4.5. This pattern is characteristic of changes caused by regulated air-handling equipment. In this case, a thermostat is regulating a furnace. The temperature changes are so small (2°F) and rapid that the RH does not vary enough to show up clearly on the chart until a larger, longer swing occurs and is mirrored in the relative humdity.

  A similar sawtooth pattern could be seen in the RH if your building had humidification or dehumidification equipment controlled by a humidistat. Cycling is generally harmful to museum materials that respond quickly to environmental change. It is also very difficult to completely elimate cycling from most ordinary HVAC equipment.

- Examine the hygrothermograph chart in Figure 4.6. You may find that changes in activity on the weekends result in a different pattern on your hygrothermograph charts. In this instance, the furnace was turned down or off. Note the resulting rise in RH over the course of the weekend. Note too, the high temperatures and the resulting low RH during the week. In this instance, lowering the thermostat setting and keeping the same setting throughout the week would be much better for the museum objects and would conserve energy.

You may need more than one hygrothermograph or datalogger for your monitoring program, especially in a historic structure located in a temperate zone where summers are hot and humid and winters are cold and very dry. You may need to place a hygrothermograph or datalogger in different spaces (for example, basement, first and second floors) to gather enough data to evaluate conditions properly.

5. *How do I use the hygrothermograph or datalogger data?*

Imagine that the record reveals that the conditions within the structure are too damp for most environmentally sensitive objects (for example, furniture and wooden objects, textile and paper objects). Probably the basement will have consistently high RH levels, the first floor will be somewhat drier, and the second floor might be drier than the first floor. If you do find that the building is too damp, there may be problems in your collections. You will need to look with a critical eye for evidence of mold and insect activity and/or damage and for sources of moisture in the structure's walls and basement. For example, rainwater runoff from the roof may be entering the basement through deep window wells and masonry cellar walls.

Once you identify the problem you must take action. While waiting for modifications to correct the runoff problem, you could put a dehumidifier and fans in the basement. Be sure to seek advice on correcting the problem from others who can help including: your regional/SO curator, conservators, historic architects, cultural resources specialists, and maintenance staff.

6. *How do I organize and summarize the data from my hygrothermograph charts or datalogger graphs?*

You must organize the data recorded by each hygrothermograph or datalogger to make it useful in developing strategies. Keep a record of daily observations, noting occurrences, such as, unusual exterior climatic conditions, a leaky roof, re-calibration of the equipment, or an unusual visitation pattern. At the end of each month when you remove the hygrothermograph chart or download datalogger data, compare this information to the daily record. It may help to record unusual occurrences directly on the chart or graph so that it is easy to see how the environment affected temperature and relative humidity.

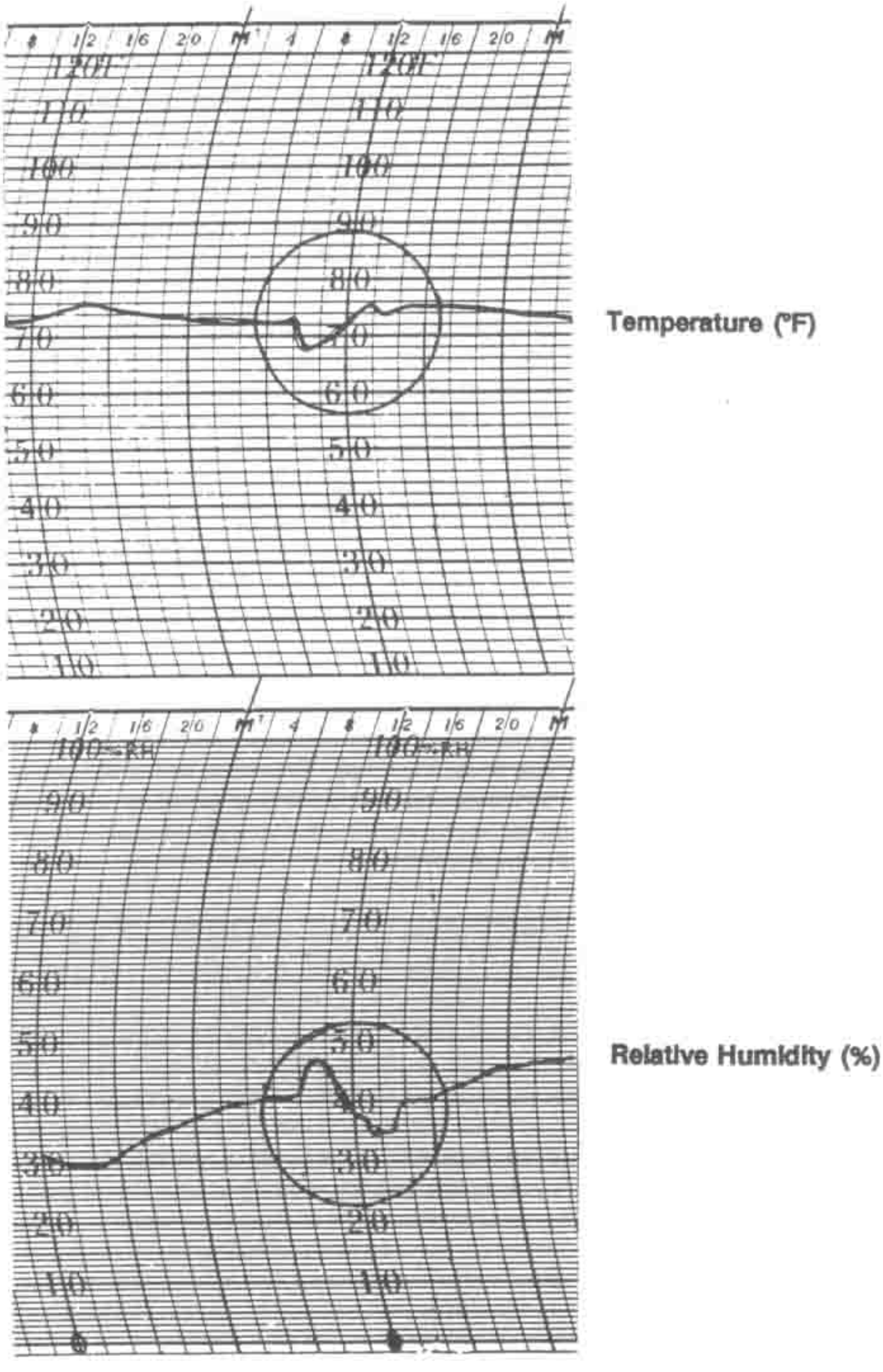


Figure 4.4. Hygrothermograph Chart that Illustrates the Relationship Between Temperature and Relative Humidity

Figure 4.6. Hygrothermograph Chart that Illustrates the Results of Turning off the Furnace

NATIONAL PARK SERVICE
MUSEUM ENVIRONMENTAL MONITORING RECORD

Col. 1	Col. 2	Col. 3		Col. 4		Col. 5		Col. 6
		EXTERNAL		CONTROLS		INTERNAL		REMARKS
DATE	TIME	TEMP	RH	TEMP	RH	TEMP	RH	

Figure 4.7. Museum Environmental Monitoring Record

7. *How do I summarize long-term data?*

You can use a table or graph to summarize relative humidity and temperature data. One way is to prepare a table that records information collected over a period of time (for example, four to six weeks). You can put the following information in a table:

- high temperature
- low temperature
- maximum diurnal (24 hour) temperature change
- high relative humidity
- low relative humidity
- maximum diurnal relative humidity change

The following example shows this information recorded for two hygrothermographs in separate museum storage spaces in the park.

Monthly Summary of Temperature and Relative Humidity			
Chart Date	**Data**	**Storage #1**	**Storage #2**
5/18-6/15/99	high temperature	29°C (84°F)	28°C (83°F)
	low temperature	21°C (69°F)	19°C (66°F)
	max. 24 hr. temp. change	4°F	4°F
	high RH	54%	56%
	low RH	45%	46%
	max. 24 hr. RH change	4%	3%

You can also summarize the data using graphs. You can design your graphs in a variety of ways. For example:

- Record both temperature and relative humidity on the same graph.
- Record temperature for several different floors of a historic structure.
- Compare temperature or RH parameters set for a building against recorded data.

You can also summarize data by preparing room-by-room records for a year. Each week, for each room or space:

- Record high/low readings for temperature and relative humidity.
- Record fluctuation patterns of temperature and relative humidity by correlating with the time of day.
- Note maximum diurnal RH fluctations.

For example:

Furnished Historic Structure	
Room A	Temperature: 18°-22°C (64°-71°F)
5/18-5/24	Gradual rise in relative humidity through week; no rapid fluctuations
	Gradual daily fluctuations from 18°(64°F) to 22°C (71°F); low about midnight, high around 3 p.m.
	Relative Humidity: 22%-32% RH
	Maximum diurnal fluctuations: 10% RH

You should summarize data gathered from instruments and recorded on your monitoring record. This helps you evaluate long-term trends and watch for problems. Summary information helps you develop new environmental control measures.

You can summarize your data for each space by season in the same format as above. A summary gives you an idea of the variation that you have throughout the year.

Use the summary documents in a variety of ways:

- Identify problems with your environment.
- Build an argument about the need to get environmental upgrades or a new building.
- Evaluate whether or not changes you have made really do improve the environment.

8. *How do I control temperature and relative humidity?*

General considerations: When you control the climate surrounding museum objects, you provide a stable environment that eliminates rapid fluctuations and extremes in temperature and RH. When you develop a strategy to control the environment in your museum spaces, keep the following points in mind:

- NPS units are located in many different climate zones, so you must develop acceptable ranges and limits of relative humidity for your individual park. There is no general solution to controlling your relative humidity. Every situation presents different variables that you must evaluate before setting standards. Base your standards on:
  - the local climate (for example, tropical, temperate, arid)
  - the nature and condition of the materials in your collection
  - the nature and condition of the structure housing the collection

- – the ability of HVAC equipment to maintain the standard

- – the ability of staff to maintain equipment

- In order to develop an effective control program, you must have good information. Collect data for one year before establishing acceptable ranges and limits.

- Use a team approach in controlling relative humidity. Once you have gathered your data, discuss control strategies with your regional/SO curator, and others, such as conservators, historic architects, and mechanical engineers. Strategies for controlling levels of RH and temperature should keep energy costs in mind. Refer to Director's Order #28: *Cultural Resource Management Guideline* for guidance.

- You will need to develop both active and passive measures for controlling the environment. When adapting a historic structure explore the use of simple modifications to your structure or space and employ portable mechanical equipment (humidifier, dehumidifier, heater, and air conditioner) or passive storage controls.

- Once you have implemented strategies to improve the environment, continue monitoring to evaluate whether or not your strategies are working.

Maintain building envelope: With the help of your maintenance division examine the structure and/or museum space for possible sources of moisture. You must eliminate sources of moisture by repairing the structure or correcting drainage problems. Problems that may cause high levels of relative humidity include:

- leaking roof, ceiling, or windows
- gaps in walls, floors, or foundation vapor barrier
- leaking plumbing
- damaged gutters and downspouts
- wet walls and foundations from poor drainage
- open water sources such as sinks or toilets

Passive methods of control: There are a variety of practices that you can adopt to passively control the temperature and RH. Carefully develop a plan to use passive controls. After adopting the practice, continue to monitor to be sure that the action improves that environment the way you expect it to.

- Avoid turning HVAC equipment on during the day and off at night. This practice causes daily fluctations in RH levels.

- Limit the number of people in a room. Large groups of people can raise the relative humidity from moisture introduced by breathing and perspiring. You may have to open doors within a building to change the circulation of the air.

- Locate sensitive objects away from spotlights, windows, exterior walls, air vents, and entrance doorways. You can also limit increased temperatures caused by the sun by using existing blinds, curtains, drapes, or exterior shutters.

- In temperate zones, reduce temperature levels during the winter. Lowering the set point of the heating equipment by several degrees raises the interior relative humidity to stabilize conditions overall. **Note:** Gradually reduce the temperature over a period of weeks. In the spring, gradually raise the temperature back to the appropriate set point. See the next section for a more in-depth discussion of humidistatic control.

- Store objects in cases, boxes, and folders. Containers are a very effective method of buffering temperature and RH fluctuations. They also limit light damage and protect collections from pests.

- To control relative humidity levels for sensitive objects (for example, some metals, textiles, paper, pyritic mineral, and fossil specimens) you may need to create a microenvironment to stabilize and maintain conditions that are different from the general museum environment. The use of a properly sealed storage cabinet or exhibit case with buffering material (for example silica gel) can provide a proper microclimate for sensitive objects. Refer to *Conserve O Gram* 1/8, "Using Silica Gel in Microenvironments" for guidance on using silica gel. There are a variety of other materials that can be used to produce microenvironments for storage of particularly sensitive objects. Consult with a conservator to discuss various options for your particular problem.

- Many materials in a museum environment absorb water and give off water. This slows changes in RH and *buffers* the environment around the object. Damage can be limited by slowing down RH changes. Natural organic materials (wood, textiles, cotton, and paper) are especially good at buffering. You can use this property to help limit changes in an environment. For example, when packing objects for shipping, wrap them in layers of paper and use pads of paper to fill the box and limit RH changes.

Active methods of control. A properly designed heating, ventilation and air conditioning (HVAC) system can maintain appropriate levels of relative humidity and temperature and filter particulate gases from the air.[2] Installing an HVAC system that achieves and maintains the environment to the levels described in this chapter is not easy. In some cases, especially with historic buildings, this approach can be detrimental to the historic building. Before embarking on a program to install, upgrade, or design a new HVAC system, assemble a team of experts and plan a system that protects both the collections and the museum building. Choose team members with expertise in historic collections care, preservation, mechanical, electrical, and structural engineering.

You must have good information from your ongoing monitoring program to help you identify the needs and problems of your current system. Working from this information, your team can design a practical system that will preserve both the collection and the building.

In some cases, you may choose to use portable humidifiers, dehumidifiers, heaters, and air conditioners. In the short-term this equipment can do a lot to improve the environment in a museum collection space. It is also less expensive than installing a new HVAC system. Refer to the NPS *Tools of the Trade* for sources of equipment.

- **Humidifiers** quickly add moisture to the air. Use a humidifier in the winter to counteract the drying effect of a central heating system. Use only an unheated evaporative humidifier. This type of humidifier does not disperse minerals in the air, and if the humidistat (a switch that turns off the equipment when a certain RH is reached) malfunctions, this type of humidifier will not raise the RH level above 65-70%. Be sure air is well circulated. You may have to use fans for circulation. You must select the size and number of humidifiers based on the size of the space, the air exchange rate, differences between the inside and outside of the building, and the number of people using the room. The *Humidification Handbook*[3] listed in the bibliography provides useful information about humidification.

- **Dehumidifiers** remove moisture from the air and lower the RH. Don't use this equipment as a permanent corrective measure – instead, find out why the air is so damp and work to remove the source of the water. There are two types of dehumidifiers:

  - Refrigerant dehumidifiers work on the same principle as a refrigerator. Cool air cannot hold as much moisture as warm air and it condenses within the machine. Use this type of dehumidifier in warm climates. You must drain dehumidifiers at least daily.

  - Desiccant dehumidifiers force air through a moisture-absorbing material (for example, lithium chloride) to reduce moisture. Hot air is blown over the desiccant to regenerate it. Desiccant dehumidifiers are useful in colder areas where refrigerant dehumidifiers may ice up and stop working.

The *Cargocaire Dehumidification Handbook* is a basic sourcebook for understanding dehumidification.[4]

9. *What are humidistatically controlled heating and ventilation systems?*

Humidistatic control is a way to control relative humidity in a building without using a HVAC system. The basic idea behind humidistatic control takes advantage of the inverse relationship between temperature and relative humidity.

Humidistatically controlled heating is based on the idea that if the absolute humidity of a given volume of air changes, it is possible to maintain a stable RH by manipulating and varying the temperature. A humidistat sensor adjusts the temperature up and down to maintain a stable RH. If the RH rises above a set point, the heat is turned on until the RH drops back down. However, using this system, temperatures can drop very low, so this type of environmental control system is best used in areas that are infrequently accessed.

Humidistatically controlled ventilation is used in areas with high relative humidity. If interior RH is lower than exterior RH, dampers are opened by sensors and the air is circulated through the building. If exterior RH is too high, the dampers remain closed.

Both of these techniques may be cost effective ways of improving the environment in historic buildings that were not built to house museum collections. They are generally less intrusive to the building fabric, and maintenance and energy costs are lower than typical HVAC systems. If you are considering using humidistatic controls work with an engineer or architect who has experience with the technique.

10. *What is the time-weighted preservation index (TWPI)?*

The time-weighted preservation index is a mathematical model developed to estimate how long some organic materials will last at certain temperature and RH levels. Using the TWPI you can make educated decisions choosing a setpoint for RH and temperature in your collection.

The TWPI was developed specifically for paper-based collections and is more commonly used for archives and libraries. It may not be appropriate for mixed collections found in many NPS parks, though its use in various types of collections is being actively researched. However, you can use it to develop microenvironments, or separate storage rooms for your paper and photo collections. See the reference by James Reilly et al. (1995) for a complete discussion of the TWPI.

F. Light

Light is another agent of deterioration that can cause damage to museum objects. Light causes fading, darkening, yellowing, embrittlement, stiffening, and a host of other chemical and physical changes. This section gives an overview of the nature of light. It will help you understand and interpret monitoring data and the standards given for light levels in museum storage and exhibits.

Be aware of the types of objects that are particularly sensitive to light damage including: book covers, inks, feathers, furs, leather and skins, paper, photographs, textiles, watercolors, and wooden furniture.

1. *What is light?*

Light is a form of energy that stimulates our sense of vision. This energy has both electrical and magnetic properties, so it known as electromagnetic radiation. To help visualize this energy, imagine a stone dropped in a pond. The energy from that stone causes the water to flow out in waves. Light acts the same way. We can measure the "wavelength" (the length from the top of each wave to the next) to measure the energy of the light. The unit of measurement is the nanometer (1 nanometer (nm) equals 1 thousand millionth of a meter). We can divide the spectrum of electromagnetic radiation into parts based on the wavelength. The ultraviolet (UV) has very short wavelengths (300-400 nm) and high energy. We cannot perceive UV light. The visible portion of the spectrum has longer wavelengths (400-760 nm) and our eyes can see this light. Infrared (IR) wavelengths start at about 760 nm. We perceive IR as heat.

The energy in light reacts with the molecules in objects causing physical and chemical changes. Because humans only need the visible portion of the spectrum to see, you can limit the amount of energy that contacts objects by excluding UV and IR radiation that reaches objects from light sources.

All types of lighting in museums (daylight, fluorescent lamps, incandescent (tungsten), and tungsten-halogen lamps) emit varying degrees of UV radiation. This radiation (which has the most energy) is the most damaging to museum objects. Equipment, materials, and techniques now exist to block all UV. No UV should be allowed in museum exhibit and storage spaces.

The strength of visible light is referred to as the *illumination level* or *illuminance*. You measure illuminance in *lux*, the amount of light flowing out from a source that reaches and falls on one square meter. We measure illuminance in museums because we are concerned with the light energy that falls on our objects, not how much light energy comes from the source. When you measure light levels (see Section H), hold your meter at the surface of the object to catch the light that is reaching that surface.

Illuminance was previously measured in *footcandles*. You may find older equipment or references that list footcandle levels. Ten footcandles equal about 1 lux.

When considering light levels in your museum you should keep in mind the "reciprocity law."

The reciprocity law states, "Low light levels for extended periods cause as much damage as high light levels for brief periods."

The rate of damage is directly proportional to the illumination level multiplied by the time of exposure. A 200-watt light bulb causes twice as much damage as a 100-watt bulb in the same amount of time. A dyed textile on exhibit for six months will fade about half as much as it would if left on exhibit for one year. So if you want to limit damage from light you have two options:

- reduce the amount of light
- reduce the exposure time

Note: Even small amounts of light will cause damage. Damage as a result of exposure to light is cumulative. It cannot be reversed. However, you can stop the continuation of damage by placing an object in dark storage. Cases, boxes, and folders are the first defense against light damage.

If lighting is too close to or focussed on an object, IR can raise the temperature. It may also lower the water content of porous materials. You can get heat buildup from:

- sunlight
- incandescent spotlights
- fluorescent ballasts
- lights in closed cases

Design exhibits so there is no heat buildup from IR generated by lights.

2. *What are the standards for visible light levels?*

You can protect your exhibits from damage caused by lighting by keeping the artificial light levels low. The human eye can adapt to a wide variety of lighting levels, so a low light level should pose no visibility problems. However, the eye requires time to adjust when moving from a bright area to a more dimly lighted space. This is particularly apparent when moving from daylight into a darker exhibit area. When developing exhibit spaces, gradually decrease lighting from the entrance so visitors' eyes have time to adjust. Do not display objects that are sensitive to light near windows or outside doors.

See the next section for ideas on how to control visible, UV, and IR light.

Basic standards[5] for exhibit light levels are:

- **50 lux maximum** for especially light-sensitive materials including:
  - dyed organic materials
  - textiles
  - watercolors
  - photographs and blueprints
  - tapestries
  - prints and drawings
  - manuscripts
  - leather
  - wallpapers
  - biological specimens
  - fur
  - feathers
- **200 lux maximum** for less light-sensitive objects including:
  - undyed organic materials

- oil and tempera paintings
- finished wooden surfaces

- **300 lux** for other materials that are not light-sensitive including:
  - metals
  - stone
  - ceramics
  - some glass

In general don't use levels above 300 lux in your exhibit space so that light level variation between exhibit spaces is not too great. With this method, people's eyes will not have to keep adapting to changing light levels, and they will be able to see objects exhibited at lower levels much more easily.

These standards should serve as a starting point for developing lighting standards for your collections. In order for collections to be seen and used in various ways (for example, long-term exhibit, short-term exhibit, research, teaching) you should take into account a variety of factors:

- light sensitivity of the object
- time of exposure
- light level
- type of use
- color and contrast of object

For example, if a researcher needs to examine fine detail in the weave of a textile, but will only be working on the object for one day you should allow more light (up to 1350 lux) than if the same textile were going on exhibit for two years.

Note: These light levels are a compromise between the need to see exhibits and the need to preserve the objects. All light exposure will cause damage to sensitive objects. There is no minimum level where damage will not occur.

See references in the bibliography for more information on light and designing appropriate lighting for your exhibit and storage areas.

G. Monitoring and Controlling Light

To be sure that light levels are at required levels and to be sure that any UV filtering material is still effective, you should measure light levels at least once a year. If you change lighting fixtures, take new measurements to be sure the changes are within recommended levels. If the source of light is daylight (for example, in a historic house museum) you should measure light in the morning and afternoon throughout the seasons.

1. *How do I monitor light levels?*

You monitor light levels using specialized equipment. This equipment is necessary because your eye is not a reliable guide as it easily adapts to changes in visible light and can't see UV or IR light. Use a visible light meter to measure visible light and a UV meter to measure ultraviolet light. Use a thermometer to measure heat buildup from IR. Several different meters are available for measuring visible and UV light. See NPS *Tools of the Trade* for sources for light monitoring equipment.

- **Visible Light Meter:** Use a visible light meter to measure the visible portion of the electro magnetic spectrum. If you purchase a new meter, you should be sure to purchase one that measures in the standard unit, lux. The meter you choose should be sensitive enough to measure light levels as low as 25 to 50 lux with a reasonable degree of accuracy (10% or better).

- **Ultraviolet Meter:** The Crawford UV Monitor is the standard piece of equipment used in museums for measuring UV levels. This monitor gives UV readings in microwatts per lumen. Older models depended on adjusting a knob until one red indicator light jumped to another light, giving a fairly inaccurate measure. Newer models are more accurate, providing the reading on a direct analog scale. There are also models of UV meters from different manufacturers that will provide a digital readout.

Use a standard set of procedures when monitoring light levels with either piece of equipment. Aim the sensor toward the light source so you are catching the light that is hitting the object you are monitoring. Be sure no shadows from your hand or body are in the way. Make sure the sensor is parallel to the surface of the object and aimed toward the light source. If the object is larger than about one foot square, take several readings. Before using any equipment, carefully read the manufacturer's instructions for operation and maintenance.

2. *How do I improve the lighting to minimize damage to objects on exhibit or in storage?*

You should develop a plan of action first, to determine if a lighting problem exists, then to determine the cause, and solutions to correct the problem. To develop your plan you first need to collect information, evaluate the data, and then develop solutions to problems that you find.

Obtain and record the following information:

- types of existing lighting fixtures, ballasts, and filters

- movement of sunlight in the room throughout the day

- seasonal variations in light

- unusual events that occur (for example, filming in a historic structure, drapes removed for cleaning)

Once you have identified the types of light and variations in lighting, you need to evaluate how light may affect the objects. Identify museum objects that are most susceptible to light damage and establish monitoring sites nearby. You will use these same sites for each monitoring session. Abandon old sites and establish new ones as conditions change. Document your monitoring and any corrective actions that you take:

- Prepare a floor plan for each exhibit or storage space that indicates the location of each monitoring site.

- Record data on the Light and Heat Measurement Record illustrated in Figure 4.8.

- Note any corrective actions taken in the comments section, for example:

  – curtains drawn

  – historic awnings replaced

  – UV filtering film installed over windows or fluorescent tubes

  – electric voltage stepped down

  – light fixtures replaced

  – new procedures to turn off lights when room is not in use

3. *How do I limit light damage from research use?*

When historic objects, archival materials, and natural history specimens are used by researchers they are exposed to light. Set up separate work spaces and research rooms so that your entire collection is not exposed to light when people are working with individual objects. Incorporate the following practices into research room use to limit the damage that occurs from this use.

- Develop procedures so that collection items are exposed to light only while the researcher is using them.

  – Keep documents in boxes or folders.

  – Remove objects from cabinets only when the researcher is ready to work.

- Limit the number of times an individual document can be photocopied.

See *Museum Handbook*, Part III, Appendix D: Planning a Research Space, and *Conserve O Gram* 19/7, “Archives: Reference Photocopying,” and 4/14, “Planning a Research Space,” for more information on limiting light damage from collection use.

Evaluate the data you collect using the Light and Heat Measurement Record. Look carefully at the information and use it to decide how to minimize the damage from light. You may want to consult the regional/SO curator and/or a conservator for help with your evaluation. Think about the following:

- Which areas have acceptable levels of light for the objects? How long have objects been on exhibit in these areas? Do they show signs of damage? Remember, not all damage can be detected by visual inspection.

- Which areas have light levels that are too high? You will need to make changes in these areas and evaluate whether your changes have helped. For example, if UV filtering film is installed on glass window panes, monitor for UV before and after application. Has the UV been eliminated? Has it affected visible light? Does the visible light still exceed the standard?

- Compare existing light levels with historic lighting conditions. Do objects on exhibit receive more or less light than they did historically? Will reducing light levels in a historic structure improve the interpretation of the building and the collection, and at the same time improve preservation?

- How often are collections used? Where and how are they used? What levels and duration of light exposure do they normally receive? Can you reduce light levels in research rooms to improve preservation and still provide adequate access?

- How often are archival collections copied? Can you produce a ‘duplication master’ so that originals will not have to be continuously copied?

You should keep the data you collect. It can help you make a case for needed changes in lighting or removal of threatened objects. Keep a permanent file of all light monitoring data.

4. *How do I fill out the Light and Heat Measurement Record?*

Follow these instructions for filling out the Light and Heat Measurement Record shown in Figure 4.8. You should use building floor plans in conjunction with this record.

- Identify the park and structure in the appropriate blocks.

- Enter the day, month, and year, and the time of day in the appropriate blocks.

- On the building floor plan enter a number at a light measurement site. Enter this station number on the Record in the Location block.

- Record the ultraviolet light reading from the UV meter. If the reading is above 75 microwatts per lumen, you should take corrective action.

- Record the visible light reading from the visible light meter in the Lux block. If you are using a meter that records in footcandles, convert to lux by multiplying by 10 (1 footcandle = approx. 10 lux).

- Record the temperature in the Temperature block.

- Record any information about the type of light source, the weather, and other comments in the comments box. Record any unusual circumstances in this block.

NATIONAL PARK SERVICE **LIGHT AND HEAT MEASUREMENT RECORD**					
Structure: ***Historic Exhibit Building***					
Date	Time	Location	UV Reading (µw/lumen)	LUX Reading	Room Temp.
4/11/99	***11:00***	***Dining Room table in front of bay window***	***10***	***100***	***68***
Comments: ***Cloudy day, drapes open***					
5/10/99	***11:30***	***Same as above***	***10***	***75***	***70***
Comments: ***Bright hot day, drapes closed***					
6/11/99	***1:30***	***Same as above***	***100***	***100***	***68***
Comments: ***UV filtering film is peeling in one corner of window, cloudy day, drapes open***					
Comments:					
Comments:					
Comments:					
Comments:					
Comments:					

Figure 4.8. Example Light and Heat Measurement Record

5. *Is there any way to directly monitor light damage?*

You can directly monitor light damage by using Blue Wool light standards. Blue Wool light standards are specially dyed textiles made so that the most sensitive sample fades in half the time needed to fade the next most sensitive sample. There are eight samples to a set. You can use the Blue Wool standards in two ways:

- Place one set of standards at the place you want to measure. Place another set in total darkness.
- Place aluminum foil over one half of a set of standards.

By comparing the two sets of standards, or two halves of one set, you can determine the light fastness of a material. The standards will not help you estimate how much exposure to light a material will stand in a particular situation. You can use Blue Wool standards to help you make an argument that light damage is occurring and that changes are needed to protect museum objects.

6. *How do I control light levels?*

All light causes damage and the damage is cumulative. Therefore, you must control all light in museum spaces that contain museum objects. There are several control methods that you can use. Be creative and use a variety of strategies to minimize light. Always monitor before and after to be sure that your changes have really helped. Remember, your eye is not a good tool for measuring light levels—use monitors.

Visible light must be maintained at or below the recommended levels. You can obtain these levels using any of the control methods below:

- Use window coverings such as blinds, shades, curtains, shutters, and exterior awnings. Close window coverings as much as possible to prevent light from reaching museum spaces. If windows must be uncovered for visitors, install UV filters and work out schedules so that windows are uncovered for only part of each day.
- Use opaque dust covers (for example, cotton muslin or Gortex®) to cover light-sensitive objects, including floor coverings. Dust covers should be used whenever visitors are not present for extended periods. They are useful in storage areas and exhibit areas that are not open to the public for part of the year.
- You can use tinted light filters (for example, films or glazing) on windows or over artificial lighting. Don't use reflective films or tints that call attention to the windows or are historically inappropriate. Consult the park or regional historic architect and your regional/SO curator to be sure filters are appropriate.
- You can reduce the amount of light from fixtures by using colored filters, lowering the wattage of incandescent bulbs, using fewer fixtures, using flood light bulbs instead of spots, and turning off lights when people are not present. You can install motion detectors in exhibit areas that activate lighting only when a person is present. You can attach timers so that lights are on only for a specific period of time.
- Use incandescent lights (which produce very little UV) instead of fluorescent lights.

Ultraviolet light should be completely eliminated. All of the techniques used to limit visible light will also cut down on UV light. To block the remaining UV light:

- Install filtering material. Refer to NPS *Tools of the Trade* for sources of UV filtering material. Types of filters include:

  – UV filtering film for windows or glass on framed objects

  – UV filtering plexiglass instead of glass

  – filter sleeves for fluorescent tubes

  – UV filtered fluorescent tubes

The plastic material that carries the UV filtering coating often breaks down faster than the filtering chemical. You should replace filters whenever they begin to turn yellow or crack. Monitor UV radiation at least every five years to be sure the filtering material is still effective.

Infrared radiation (heat) generated by natural or artificial lighting should also be controlled to prevent rapid changes in relative humidity. Window coverings and filters and good air circulation systems (for example, fans and air conditioners) help control heat buildup. You can control the heat produced by artificial lighting fixtures by using filters and good air circulation systems, as well as keeping lights outside exhibit cases.

Floodlights used for professional and motion picture photography and photocopy machines can cause excessive heat buildup. Discourage photography in museum storage areas. When photography is allowed in museum areas request heat absorbing light filters and be sure the area is well-ventilated with fans or air conditioners. Lights should be turned off whenever filming is not taking place. If lighted rehearsals are necessary, use dummy objects until the final filming will take place.

H. Dust and Gaseous Air Pollution

Air pollution comes from contaminants produced outside and inside museums. Common pollutants include: dirt, which includes sharp silica crystals; grease, ash, and soot from industrial smoke; sulfur dioxide, hydrogen sulfide, and nitrogen dioxide from industrial pollution; formaldehyde, and formic and acetic acid from a wide variety of construction materials; ozone from photocopy machines and printers; and a wide variety of other materials that can damage museum collections. Air pollutants are divided into two types:

- ***particulate pollutants*** (for example, dirt, dust, soot, ash, molds, and fibers)

- ***gaseous pollutants*** (for example, sulphur dioxide, hydrogen sulphide, nitrogen dioxide, formaldehyde, ozone, formic and acetic acids)

1. *What are particulate air pollutants?*

Particulate pollutants are solid particles suspended in the air. Particulate matter comes both from outdoor and indoor sources. These particles are mainly dirt, dust, mold, pollen, and skin cells, though a variety of other materials are mixed in smaller amounts. The diameter of these pollutants is measured in microns (1/1,000,000 of a meter). Knowing the particulate size is important when you are determining the size of air filters to use in a building.

Some particles, such as silica, are abrasive. Pollen, mold and skin cells can be attractive to pests. Particulates are particularly dangerous because they can attract moisture and gaseous pollutants. Particulates can interact with gaseous pollutants and cause deterioration in three different ways. Particulates may be:

- a source for sulfates and nitrates (These particles readily become acidic on contact with moisture.)
- a catalyst for chemical formation of acids from gases
- an attractant for moisture and gaseous pollutants

2. *What are gaseous air pollutants?*

Gaseous pollutants are reactive chemicals that can attack museum objects. These pollutants come from both indoor and outdoor sources.

Outdoor pollutants are brought indoors through a structure's HVAC system or open windows. There are three main types of outdoor pollution:

- sulfur dioxide (SO_2), and hydrogen sulphide (H_2SO) produced by burning fossil fuels, sulfur bearing coal, and other organic materials
- nitrogen oxide (NO) and nitrogen dioxide (NO_2), produced by any kind of combustion, such as car exhaust as well as deteriorating nitrocellulose film, negatives, and objects
- ozone (O_3), produced by sunlight reacting with pollutants in the upper atmosphere and indoors by electric or light equipment, such as photocopy machines, printers, some air filtering equipment

When sulfur and nitrogen compounds combine with moisture and other contaminants in the air, sulfuric acid or nitric acid is produced. This acid then causes deterioration in a wide variety of objects. Ozone reacts directly with the objects causing deterioration.

The main sources of **indoor air pollution** come from building materials and include:

- wood, which can release acids
- plywood and particle board, which give off acids from wood and formaldehyde and acids from glues
- unsealed concrete, which releases minute alkaline particles

- some paints and varnishes, which release organic acids, peroxides, and organic solvents

- fabrics and carpeting with finishes, such as urea-formaldehyde, and wool fabrics that release sulfur compounds.

- glues, used to attach carpets, that can release formaldehyde

- plastics that release plasticizers and harmful degradation products such as phthalates and acids

Museum objects themselves may also contribute to indoor air pollution. For example, many plastics are inherently unstable and as they deteriorate they give off acidic by-products. Examples of sources of pollutants from museum objects include:

- celluloid and other unstable plastics used to produce many 20^{th}-century objects

- cellulose nitrate and diacetate plastic, used for film

- pyroxylin impregnated cloth used for book bindings

- residual fumigants, such as ethylene oxide

Object Materials	***Deterioration***	***Primary Air Pollutants***	***Environmental Factors Accelerating Damage***
metals	corrosion/tarnishing	sulfur oxides and other acidic gases	water, oxygen, salts
stone	surface erosion, discoloration	sulfur oxides and other acidic gases, particulates	water, temperature fluctuations, salt, vibration, microorganisms, carbon dioxide
paint	surface erosion, discoloration	sulfur oxides, hydrogen sulfide, ozone, particulates	water, sunlight, microorganisms
textile dyes and pigments	fading, color change	nitrogen oxides, ozone	sunlight
textiles	weakened fibers, soiling	sulfur oxides, nitrogen oxides, particulates	water, sunlight, mechanical wear
paper	embrittlement	sulfur oxides	moisture, mechanical wear
leather	weakening, powdered surface	sulfur oxides	mechanical wear
ceramics	damaged surface	acid gases	moisture

Figure 4.9. Deterioration to Museum Objects Caused by Air Pollution

I. Monitoring and Controlling Particulate and Gaseous Air Pollution

As with problems from other agents of deterioration, you need to monitor your collections to identify whether or not air pollution is causing damage to your collections.

1. *How do I monitor air pollution?*

There are a variety of monitoring devices that can be used to directly measure pollutants in the museum. If you feel direct measurement is needed, contact your regional/SO curator for assistance. There are other steps you can take to identify and understand air pollution levels.

- Inspect storage spaces (for example, floors, open shelving, tops of cabinets and tables) for dust. Note how much dust has built-up since the last cleaning. Watch for increased insect activity using your IPM program. Increased insect activity is often related to an unacceptable accumulation of dust.
- In coastal areas, watch for pollution from chlorides by observing and noting active corrosion on metal objects. Chlorides will react with unpainted iron or steel objects, causing rust.
- Observe and document a building's air control system and the nature of the structure. Concrete walls and adobe are sources of high levels of dust. Some concrete dating from 1940-1975 contains asbestos, making it a health risk as well as a source of particulates. Improperly filtered air intakes can transfer high levels of pollutants into museum spaces.
- Identify exhibit cases, storage cabinets, and shelving made out of untreated wood or painted with the wrong paints that can outgas formaldehyde and acetic acid.
- Watch to see how much dust and dirt is tracked into spaces by visitors and employees.

Some parks have on-going air monitoring research. You can also contact the Environmental Protection Agency (EPA), Office of Air Quality Planning and Standards to obtain information on levels of ozone, sulfur dioxide, nitrogen dioxide, and particulates recorded in the park. These data will assist park staff in identifying potential pollutant problems that may exist. Areas with high concentrations of gaseous pollutants in the air will definitely want to establish a program for monitoring signs of active deterioration on objects in museum storage and exhibit areas.

2. *Are there ways to monitor for air pollution?*

There are several ways to monitor air pollutants that are simple to use in museums. Each has good points and bad points so before you choose one method, investigate each type of monitor and evaluate the type of information you want to recover. You can get advice from a conservator or your regional/SO curator. There is more information in the bibliography on using and evaluating monitoring devices.

Oddy tests: Oddy tests have been used for some time as a simple method of evaluating materials that are used in contact with objects in storage or on exhibit. In this test, metal coupons (small samples of metal) are placed in a closed container with the material being tested and a small amount of moisture. The container is slightly heated and after a set amount of time, the metal is examined for corrosion. It gives you some idea of how 'safe' a material is and whether or not it will cause deterioration? Problems with this test include:

- unusual reactions—because heat and moisture are raised in the container, reactions may occur that would not happen in a normal museum environment

- little reproducibility—for a variety of reasons, results from this test are widely variable

Passive sampling devices: These are devices that absorb particular pollutants. They are placed in the area you want to test for some period of time and then removed and sent to a lab to be tested for presence and levels of pollutants. Each passive sampling device measures one type of pollutant. For example, one device will measure for formaldehyde, another for acetic acid. However, there are problems with these devices:

- They may require off-site analysis.

- The devices have varying sensitivities. Use devices that can detect gaseous pollutant in parts per billion (1:1,000,000,000 ppb) or lower levels.

A-D strips. These strips detect acetic acid. They were developed to detect and measure acetate film deterioration or "vinegar syndrome" in film collections. They change color as the level of acidity increases. They are used to set priorities for film reformatting.

3. *How do I control air pollution?*

The NPS standard in the Checklist for Preservation and Protection of Museum Collections on controlling air pollution states, "Eliminate gaseous and particulate pollution to the lowest practical level." There is no minimum acceptable level of pollution. You can do the following to reduce levels of air pollution:

- In storage spaces, keep floors, tops of cabinets, and work surfaces clean to minimize dust accumulation. Work with custodial staff to keep areas clean. Use high efficiency particulate air (HEPA) vacuums which catch more particulates. Regular vacuum cleaners simply throw many smaller particles up into the air.

- Separate office and curatorial work spaces from museum collections storage spaces. Areas that are not accessed often will stay cleaner than high traffic areas.

- Upgrade and maintain seals and weatherstripping around doors and windows to keep pollutants out.

- Store sensitive objects in appropriate museum specimen cabinets. Maintain sound gaskets on all storage cabinets. Replace old gaskets with neoprene gaskets. Refer to NPS *Tools of the Trade* for the source of retrofit gasket kits. NPS *Conserve O Gram* 4/8 explains how to install the retrofit gasket kit.

- Store archival materials in boxes, map cases, and folders.

- Use dust covers to protect objects on open shelving. Dust cover material should be chemically and physically non-damaging and provide as complete a dust seal as possible, while allowing easy access. Use clear polyethylene sheeting, unbleached cotton muslin, Tyvek®, or Gore-Tex®. Refer to NPS *Conserve O Gram* 4/7, "Dust Covers for Steel Shelving," for additional information on constructing dust covers.

- Segregate objects that outgas pollutants (for example cellulose nitrate negatives or objects, diacetate negatives, or hardwoods such as oak, birch or beechwood) from other objects.

- Store, exhibit, and transport objects in appropriate cases. Avoid using exhibit materials (for example, hardwoods) that outgas organic acids. The adhesives used in plywood and veneers may be a source of pollutants. See Figure 4.10 for a list of both harmful and safe materials.

- In areas with high air pollution levels you may want to install pollution filtering in your HVAC system. These filters extract gaseous and particulate pollutants before they get into a museum space. Work with HVAC engineers to design a system appropriate to your facility. Do not use filtering systems that generate damaging ozone.

- You can use portable air filters with activated-carbon filters to remove particulates from the air. These filters will also remove some gaseous pollutants. Refer to NPS *Tools of the Trade* for sources for this equipment.

Storage and Exhibit Construction Materials Known to Release Harmful Substances	
Materials	***Harmful Vapors***
wood (particularly oak, birch, beech)	organic acids
wood panel products	organic acids, formaldehyde
protein-based glues, wool	volatile sulfides
vulcanized rubber	volatile sulfides
some dyes	sulfur compounds
cellulose nitrate	nitrogen oxides
cellulose acetate	acetic acid
polyvinyl chloride	hydrogen chloride
polyurethanes	volatile additives
Storage and Exhibit Construction Materials That Appear to be Safe	
metals	
glass	
ceramics	
inorganic pigments	
polyethylene and polypropylene	
acrylic solutions (some acrylic emulsions are suspect)	
polyester fibers	
cotton and linen	

Note: while these materials are considered safe, manufacturing processes may add coatings and additives that can damage museum collections.

Figure 4.10. Types of Materials That Can Harm Objects and Types of Materials That are Considered Safe to Use with Museum Objects for Storage and Exhibit[6]

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K. Endnotes

1. Relative humidity optimum ranges for materials included in Figure 4.2 are based on information from *Climate in Museums: Measurement* (3d ed.) by Gael De Guichen, and on information included in curatorial care appendices of this handbook.

2. *The ABCs of Air Conditioning: A Primer of Air Conditioning Types and Methods* outlines the types of air conditioning systems, introduces cooling load calculation, and compares the functioning of system types. A copy of this publication may be obtained from:

   Carrier Air Conditioning
   P.O. Box 4800
   Syracuse, NY 13221
   (315) 432-6000

3. *The Humidification Handbook: What, Why and How,* written by Bernard W. Morton, includes an introduction to humidity theory and measurement, and provides specification information on the determination of humidification load, methods of humidification, and system design considerations. It is available from:

   Dri-Steem Humidifier Company
   14949 Technology Drive
   Eden Prairie, MN 55344
   (800) 728-8336

4. *The Cargocaire Dehumidification Handbook* discusses methods of dehumidification, system design, and selection, and provides an introduction to calculations of moisture loads. A copy of this publication may be obtained from:

   Cargocaire Engineering Corporation
   79 Monroe Street
   P.O. 640
   Amesbury, MA 01913
   (800) 843-5360

5. Illumination levels are based on information in *The Museum Environment* (2d ed.), “Light,” Part I by Garry Thomson.

6. Information included in Figure 4.10 is taken from “Trouble in Store” by T. Padfield, D. Erhardt, and W. Hopwood, and "Materials for Exhibit, Storage, and Packing," by J. Tétreault and S. Williams.