https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Agents of deterioration

Understand the 10 primary threats to heritage objects and how to detect, block, report, and treat the damage they cause.

Physical forces

Learn how to avoid, detect, report and treat the damage caused by physical forces.

Thieves and vandals

Learn how to avoid, detect, report and treat the damage caused by thieves and vandals.

Fire

Learn how to avoid, detect, report and treat the damage caused by fire.

Water

Learn how to avoid, detect, report and treat the damage caused by water.

Pests

Learn how to avoid, detect, report and treat the damage caused by pests.

Pollutants

Learn how to avoid, detect, report and treat the damage caused by pollutants.

Light, ultraviolet and infrared

Learn how to avoid, detect, report and treat the damage caused by light, ultraviolet and infrared.

Incorrect temperature

Learn how to avoid, detect, report and treat the damage caused by incorrect temperature.

Incorrect relative humidity

Learn how to avoid, detect, report and treat the damage caused by incorrect relative humidity.

Dissociation

Learn how to avoid, detect, report and treat the damage caused by dissociation.

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Physical forces

Paul Marcon

Force definitions

Physical force can damage objects directly by causing rotation, deformation, stress, and pressure. It may also damage objects indirectly by causing collision between objects or object parts. Damage from physical force ranges from imperceptible hairline fissures and minute losses, to large-scale effects such as crushing objects, collapsing floors, and, in extreme cases, destroying buildings. Five important force-related effects are: impact; shock; vibration; pressure; and abrasion. Some of these effects are closely linked. They are defined as follows:

Impact is the result of something striking an object, an object striking a hard surface, or objects striking each other. Impact force can be concentrated in a small area or spread out due to the hardness and geometry of the surfaces that collide. Localized impact damage, such as small cracks, can increase the susceptibility of an object to force.

Shock is usually the result of a strong impact. It can induce large deformations and strains in objects or their parts. Shock intensity is measured in **g** units of acceleration where one **g** represents the acceleration due to the Earth's gravity. For example, if an object is subjected to a shock of 100 g, the object will sustain a force equal to 100 times its weight for a brief (several to 10 or more milliseconds) period of time. Shock can cause substantial damage to most art objects and is an important cause of damage during shipment.

Vibration is the oscillating motion of an object relative to a fixed point of reference. A vibration-prone object will vibrate freely (**free vibration**) if it is displaced from its equilibrium position and released. A tuning fork provides an example of this; it vibrates freely at one frequency after it is struck. The vibration amplitude then diminishes over time as the energy that was supplied to the tuning fork is released (Figure 1a). An object may also vibrate in response to an externally applied source of vibration (**forced vibration**) as in the case of a packaged item inside a transport vehicle. The simplest form of continuous vibration is **harmonic motion**, which consists of movement that repeats itself exactly after certain time periods, as illustrated in Figure 1b. **Random vibration** is a type of vibration found in moving vehicles and other everyday vibration sources. It is a complex combination of many vibration frequencies with randomly varying amplitudes. Figure 1c shows the appearance of random vibration on a trace of amplitude versus time.

Two basic quantities for describing vibration are **frequency** (in cycles per second or Hertz [Hz]) and **amplitude** (which can be expressed as a displacement, velocity, or acceleration). Construction vibration amplitude is expressed as particle velocity (the velocity of a particle as it transmits a wave). This measure correlates well with the development of cosmetic cracking in structures (consult the "Construction Vibration and its Effect on Buildings" section below).

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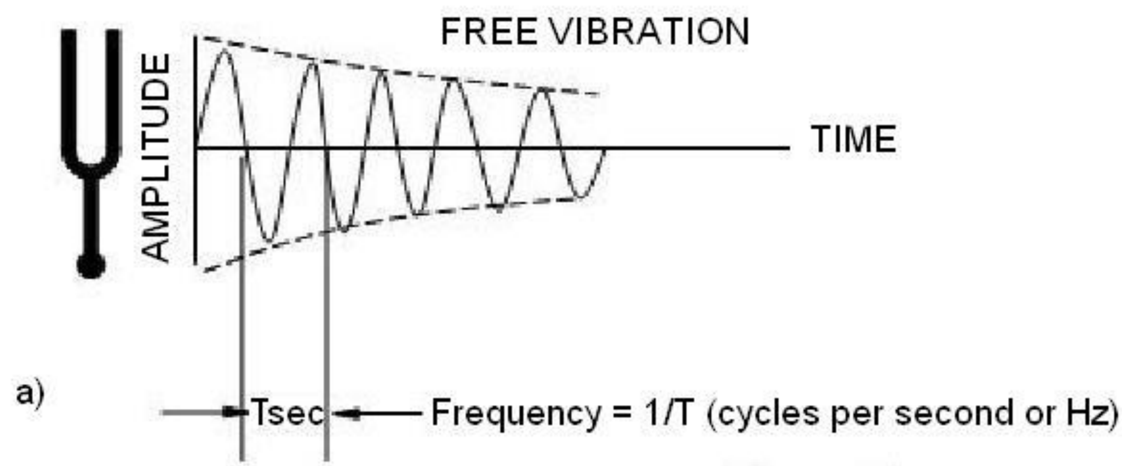

Figure 1a) Free vibration of a tuning fork. Its amplitude diminishes with time due to damping forces such as friction and air resistance that dissipate vibration energy.

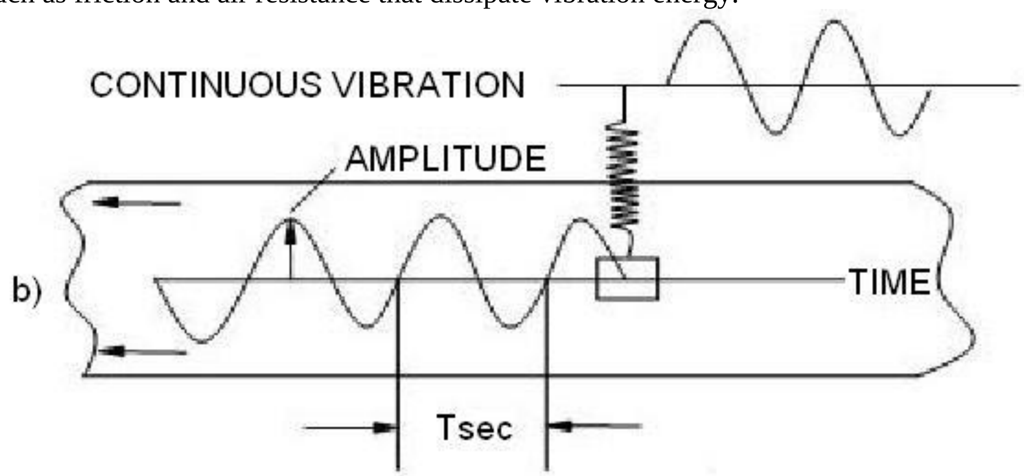

Figure 1b) Continuous harmonic vibration and its appearance as a sine curve on a record of amplitude versus time, as traced by the motion of the spring suspended mass (labeled M on the moving paper chart).

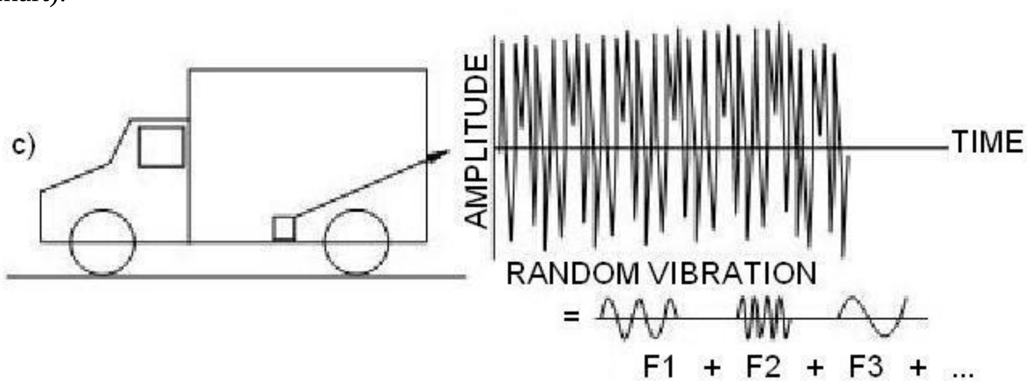

Figure 1c) Random vibration and its appearance on a graph of amplitude versus time. Random vibration data is usually converted to a frequency versus time record by analysis instrumentation. Information on the frequency components contained in a source of vibration helps assess its effect on structures.

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Pressure is the force applied on a unit area of material. Pressure may be the result of gravity or handling. It may contribute to abrasion, strain, and deformation ultimately leading to distortion or breakage. When objects or packages are stacked in storage, compressive loads are applied to the lower items of the stack. Loads on stacked items in transport will be magnified by the shock and vibration caused in moving vehicles. Shipping containers can be designed to carry these compressive loads; the ability to support a top load of 50 pounds per square foot is a common requirement for industrial crating. Pressure (or compressive load) on a flat surface can be simply calculated as force divided by the area on which the force acts. Maximizing the contact area will minimize the load per unit area — an important consideration for fragile surfaces and container top loads (e.g. skids are better at distributing the weight of an upper container onto lower containers of a stack compared to individual feet, which may concentrate the loads onto smaller portions of the supporting container).

Abrasion is possible wherever there is movement between two surfaces that are in contact. Abrasion effects will vary according to surface durability, the amount of pressure applied to the surfaces, and the profile of these surfaces. The presence of abrasive material or particles between surfaces may also cause, or accelerate, abrasion. Abrasive damage may appear after a long period of exposure to movement, but it can also occur quickly if the surface is fragile.

Direct effects of force

Force that is directly applied to an object may result incompression, punctures, dents, tears, cracks, chips, scratches, or abrasion. Gravity results in a continuous load on all objects. Substantial loads can be concentrated on object parts during handling operations (consult Figure 2). Improperly made supports may lead to distortion or permanent deformation of objects due to the effects of load concentration. Long-term loading of or short-term overloading of cushioning material results in looseness between the object and the package material, which can reduce the effectiveness of cushioning. Excessive loading of support materials, such as foam materials in storage, may lead to instability of objects. An incident in which a heavy object fell off its support, that had deformed under an excessive load, has been reported. Another incident involved a display plinth under a large marble sculpture that failed after a short period of time. The proper support for heavy items is clearly an important safety issue for staff and visitors to museums.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Figure 2. Installation photo: **Three Witches** by Anish Kapoor (1990). Specialized riggers and heavy moving equipment can move heavy objects safely while minimizing the risk of damage. Be sure to verify the floor-load capacity when moving or displaying heavy objects such as these.

Mechanical shock

Mechanical shock is an energetic response of an object. It is characterized by substantial displacements and strains. Four outcomes are possible.

1. Low levels of shock may be absorbed and dissipated in the object without damage. A bell provides an example: striking it with the right object and the proper amount of force makes it ring without any damage to the bell's surface or structure.
2. Impact may cause an object or its parts to move, resulting in collision between objects, object parts, and their surroundings.
3. High shock levels may cause movement and induce strains in excess of critical thresholds resulting in fatigue damage (explained below under the heading of vibration).
4. If the shock magnitude is high enough, damage occurs in a single event (stress fracture).

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Vibration effects on people

The full range of human perception of, and reactions to, vibration is summarized as a basis for comparison to commonly encountered vibration sources. Humans can perceive vibration at very low amplitudes in the range of 0.1 to 0.5 mm/s. Peak human vibration sensitivity occurs in the frequency range of 5 to 30 Hz, which is the same frequency range that is generated by many construction activities (Dowding 1996). This explains why concerns and complaints arise during construction work even though the vibration amplitudes generated by this activity may be relatively low.

Vibration effects on objects

Most objects are capable of vibration at many vibration frequencies due to their geometry, mass, and elasticity. The lowest vibration frequency is referred to as the **natural frequency**. Vibration tendencies at higher frequencies are called **resonant frequencies**. It is also common to refer to all these frequencies as resonant frequencies. Some examples of vibration-prone objects are illustrated in Figure 4.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

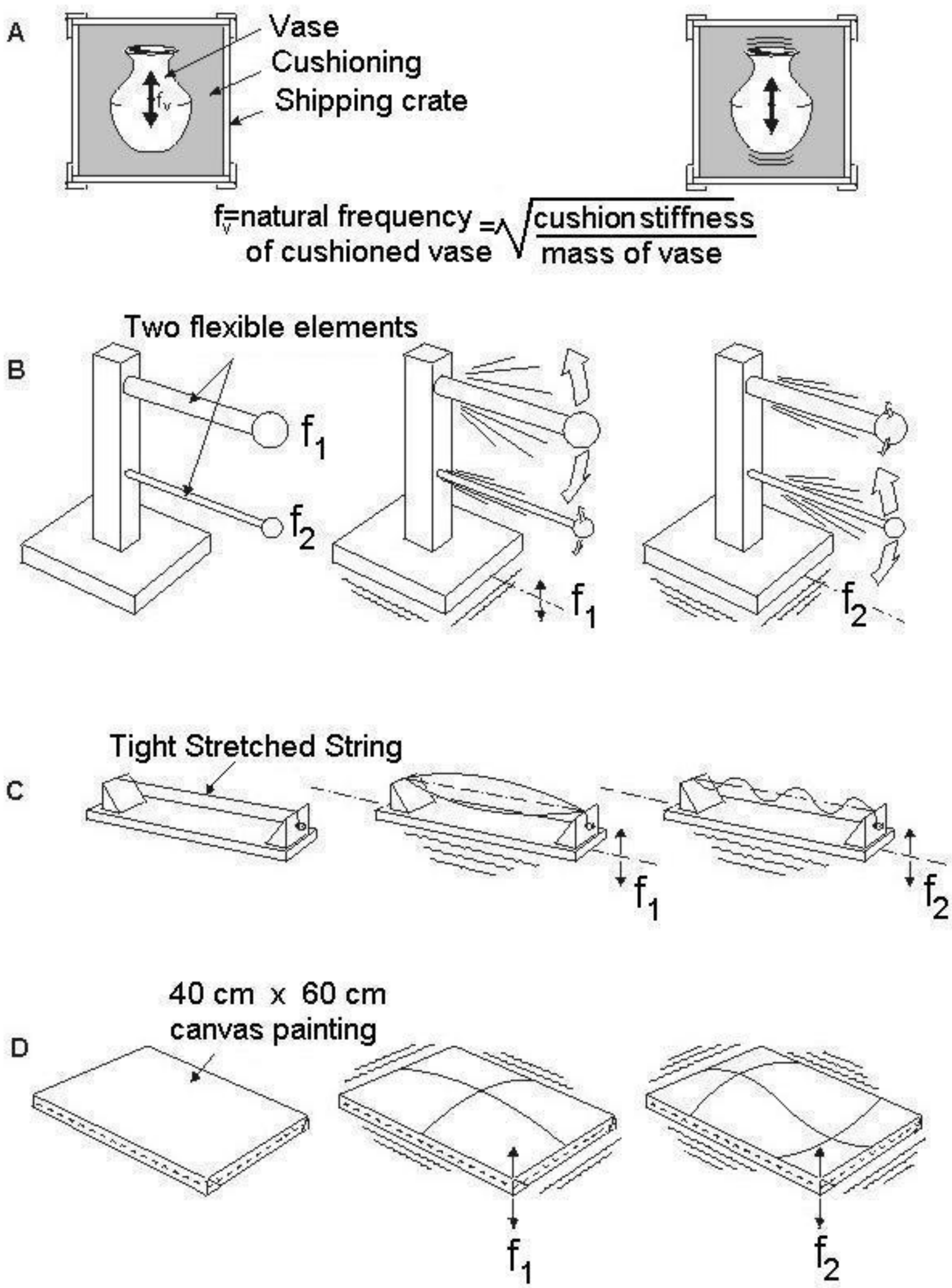

Figure 4. Examples of objects that are capable of vibration: a) a vase floated in protective cushioning has one resonant frequency along its vertical axis, $\mathbf{f}_1$; b) an object with two flexible components has two resonant frequencies, $\mathbf{f}_1$ and $\mathbf{f}_2$; c) a stretched string has many resonant frequencies; standing wave patterns for the first two, $\mathbf{f}_1$ and $\mathbf{f}_2$ are shown; and d) the first resonant frequency of a 40 x 60 cm canvas under normal tension is about 24 Hz. The next one is 32 Hz. A standing wave pattern at each frequency is shown.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

If the package containing the cushioned vase in Figure 5 is subjected to vibration, three outcomes are possible. These three conditions are described below in detail.

Transmission (Figure 5a). If the vibration frequency is lower than $\mathbf{f}_v$ ($\mathbf{f} < f_v$), the vase will vibrate at the same frequency and amplitude as the vibration source.

Resonance (Figure 5b). If the frequency of the vibration source matches the resonant frequency of the vase–cushion combination, f_v, the amplitude of the vase will be greater than the amplitude of the vibration source due to a condition known as resonance. Resonance in a cushioning system is normal. Resonant amplitude is limited by the damping properties of most cushioning materials. Package designers usually avoid having object resonances in the same range as the cushion system. Resonance is an important consideration in structures and machinery due to the force-multiplying effects of this condition.

Attenuation (Figure 5c). If the vibration frequency is greater than $\mathbf{f}_v$, attenuation takes place and the vase will appear almost motionless while the package oscillates. This is vibration isolation where frequencies greater than 2 x $\mathbf{f}_v$ will be isolated with an efficiency of 80% or more.

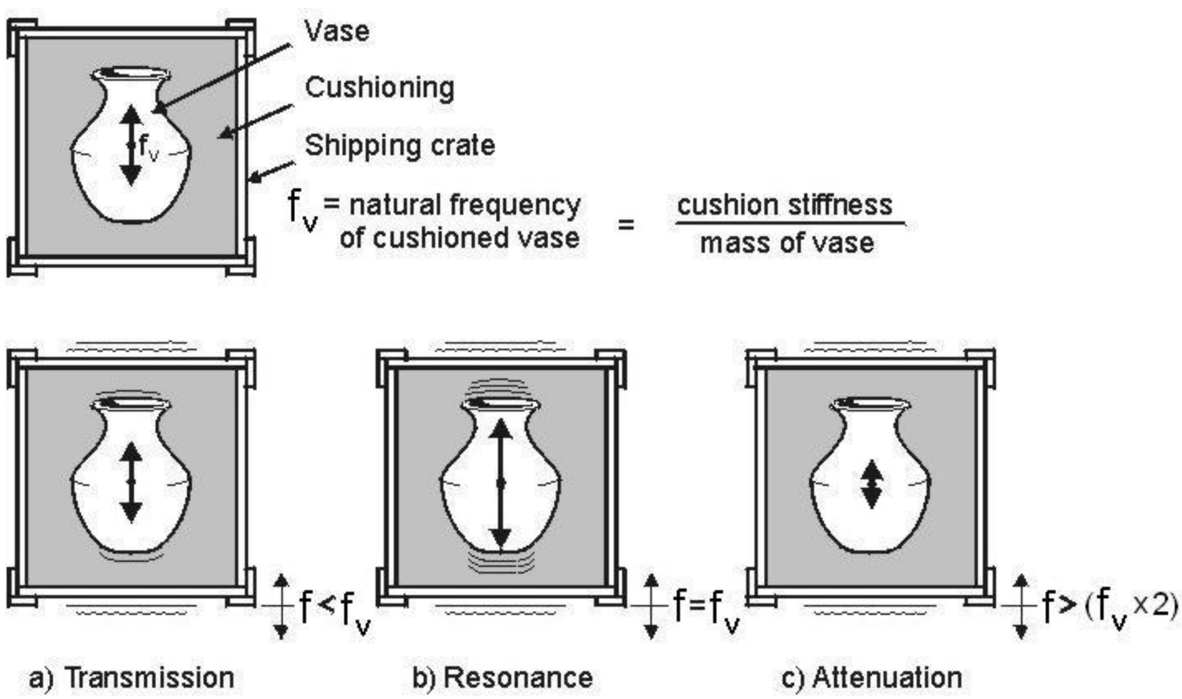

Figure 5. A vase supported on protective cushioning is a simple mechanical system with one resonant frequency (vertical axis) that is capable of vibration. When the package is subjected to a source of vibration in the vertical direction considered here, three outcomes are possible depending on the ratio of the natural vibration frequency of this system and the frequency of the vibration source: a) transmission; b) resonance; and c) attenuation.

The vase in the preceding example is essentially a rigid object; therefore, none of the vibration conditions described above are hazardous as long as the surface of the vase is durable.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Fatigue

A familiar damaging effect of vibration is mechanical fatigue. In order for this to take place, two requirements must be met. First, a critical stress threshold must be attained or exceeded during each vibration cycle. Damage then occurs after a time interval that depends on the number of vibration cycles and their peak values. The Tacoma Narrows Bridge (consult Figure 6) provides a dramatic example of this effect on a very large scale. Note that if stress levels are below a critical level, then almost indefinite cycling is possible without damage. Stress fracture on the other hand occurs in one cycle of sufficiently high stress.

While fatigue is an important issue for machinery and engineering structures, it may not be as important for museum objects in light of the low magnitude of vibration sources encountered in common situations. In experimental investigations using specially prepared canvas paintings and other small-to-medium-size objects, attempts to induce damage by vibration have usually required unrealistically high (compared to commonly encountered sources) vibration levels. The canvas painting in Figure 7 was vibrated for several days at high amplitude, but did not show clear evidence of damage when analyzed using a laser scanner. While it is not possible to apply the results of these investigations to all object classes, the results appear to support the following generalizations:

- There is not always an efficient physical connection between the object and a vibration source to effectively transmit the vibration.
- Practical sources of random vibration encountered by objects do not usually cause the sustained or energetic object responses that result in fatigue.
- Fatigue-like damage (cracks) may already be present in many objects and may be caused by the action of direct forces or other agents such as temperature and humidity cycling.
- If fatigue-type damage already exists, it would be reasonable to expect that additional cycling may contribute to additional damage in some cases.

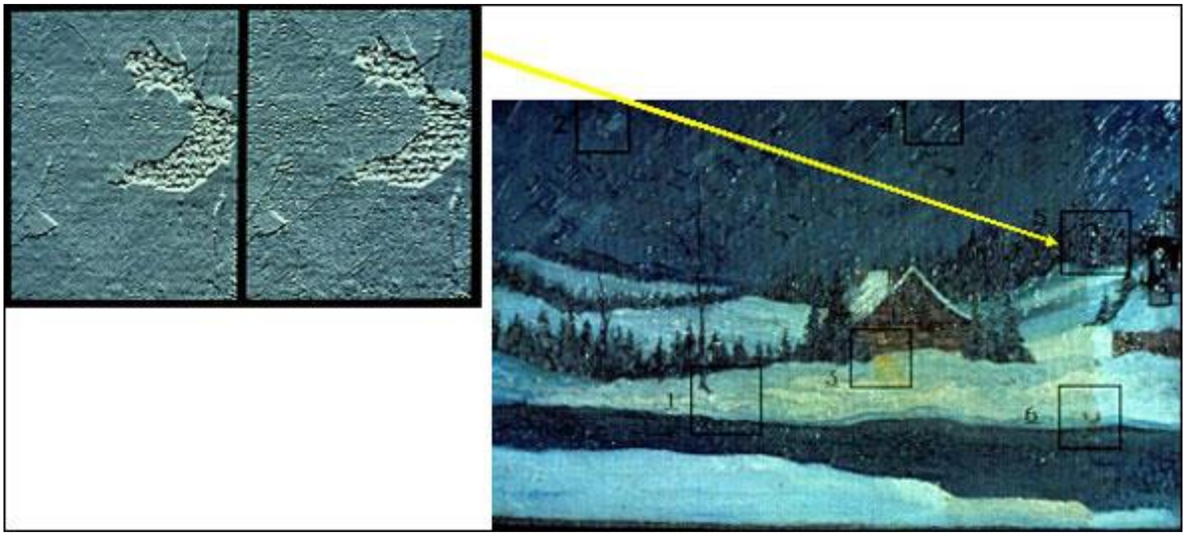

Figure 7. A small 50-year-old oil painting (approximately 20 x 40 cm), with existing losses and an extensive network of cracks, was vibrated for two days at 2 cm amplitude. Before-and-after laser scans of selected areas, such as the one shown, did not reveal conclusive evidence of additional damage. The vibration condition (sustained resonance) is much more severe that what may be expected in practice. Note that in this case, large amplitude cycling is present and, although the out-of-plane displacement of the canvas is large during each cycle, the elongation of the paint and ground layers is minimal.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Construction vibration and its effects on buildings

Damage to buildings by construction vibration appears in a form that is described as "cosmetic cracking" in the literature. It is interesting to note that this type of damage is an ongoing process for most buildings, even those located in areas free of vibration, and that temperature and humidity fluctuations (not noticed by the occupants) are important causes of this effect. The findings of 16 building damage studies from Dowding (1996) are summarized in Table 4, below.

Low-level vibration effects

Building occupants will react in situations when building vibration is perceptible or where there is some evidence of movement in object parts. Questions about possible risks to collections are often raised in these situations. One involved concerns about visible canvas movement in a collections storage room due to low-level vibration from HVAC system system components. The second involved concerns about perceptible blast-induced vibration from a rock quarry near the site and from nearby road traffic. A brick re-pointing procedure generated clearly perceptible vibration at another client's site where a fragile, hollow plaster exhibit was on loan. Neither vibration scenario was deemed to present a significant risk to the collections. While it is still advisable to investigate concerns carefully, some general opinions on the subject of low-level vibration are provided below:

- Perceptible levels of vibration from low-level sources at a reasonable distance from the vibration-producing activity may not require any corrective action. As the distance from the source to the object increases, the vibration intensity diminishes quickly as it crosses structural connections and is transmitted through building materials.
- Relocation of objects near construction operations is advisable provided that the objects can be moved without an even greater risk of damage due to handling.
- If relocation is not feasible, and the object is in contact with a surface that transmits vibration (e.g. a common floor slab), the object may be decoupled from the floor with a layer of soft cushioning material.
- Object movement (sliding) may be a concern for lighter objects weighing less than 1 kg stored or displayed on a slippery surface near internally generated sources of vibration. These objects can benefit from an interleaf or a method of restraint appropriate for the type, material, and configuration of the object such as wax or an interior restraining block.

Vibration and sensitive equipment

Research and conservation activities in museums require the use of vibration-sensitive instruments such as microscopes and precision balances (Figure 8). New building construction with long open spans between support columns and beams bridged by light construction materials will also contribute to vibration-related problems for this type of equipment. Long extension arms on microscopes can re-amplify low-level building vibrations in the instrument itself. Vibration criteria for sensitive equipment are published in standards such as those published by the International Standards Organization (ISO) and by others (Ungar 1992). Note that some instruments, such as scanning electron microscopes, will be adversely affected at levels that are far **below** those that building occupants can perceive.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

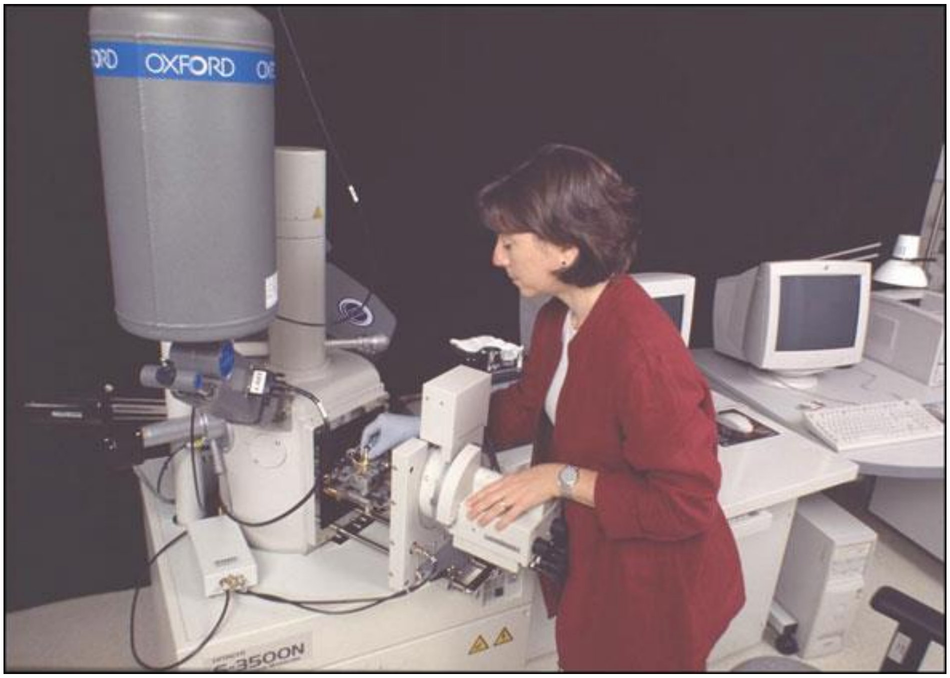

Figure 8. An electron microscope can be adversely affected by vibration levels that are far below levels that people can perceive. Other vibration-sensitive instruments, such as microscopes and precision balances, are commonly found in museums.

Acoustic effects

Occasionally, concerns are expressed about the effect of loud music on artwork. The classic case of a shattering wine glass on exposure to loud sound illustrates the structural vulnerability that is required to achieve this effect as well as the precise control and intensity of the sound source that would unlikely be duplicated in anything other than a lab setting. The sound intensity required to break fragile stemware (very fine crystal) is reported to be about 140 decibels (dB) **in the direct vicinity of the glass.** In addition to high sound intensity, breaking the glass also requires identifying a critical resonant of the glass precisely and adjusting the high-intensity vibration source to within 0.5 Hz of this frequency.

Attempts to develop non-destructive analysis methods of sample frescos and icons to detect interlayer delamination and other forms of damage required sound pressure levels of 80 to 110 dB at the fresco surface (Castellini 1999). Loudspeakers were ineffective in inducing sufficient movement in the fresco components to enable their analysis by scanning laser methods. Horns and parabolic mirrors and direct attachment of transducers were necessary in order to apply sufficient sound pressures to the areas under investigation. It is interesting to note that the goal of this analysis method was:

- to evaluate the condition of the frescoes non-destructively; and
- to seek an alternative for an expensive and time consuming manual investigation method that involves tapping small areas and sensing any vibration with their fingertips while listening to the induced sound.

This manual technique is reported to impose a peak pressure of about 30 N/cm^2 on the sampled area. Horns and speakers impose about 6.5E-04 N/cm^2 and a direct transducer attachment imposes about 0.5

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

N/cm^2. The manual investigation method also shares the goal of non-destructive condition assessment and applies force intensities to the sampled item that are about 50,000 times greater than high-intensity acoustic sources and 230,000 times greater than the force intensity imposed on the fresco samples by live music.

In summary, acoustic sources such as live music do not appear to pose a significant risk to artwork. Ordinary handling, transit vibration, and the effects of other agents will be more relevant concerns. Attempts to damage highly fragile stemware requires a combination of object vulnerability, sound intensity, and control that is not usual in commonly encountered situations. Based on the forgoing material detailing the forces imposed on fragile fresco structures from sound and other sources, ordinary handling would be a much greater concern for fragile items.

Indirect force effects

Vibration-induced movement

One of the most important vibration effects to be aware of is simply the by-product of the movement it can cause. Vibration may originate from a variety of sources; two of the more important ones are earthquakes and vibration during transport. Note that shock may also cause vibratory motion; for example, ringing a bell. Some examples of configurations that may be vulnerable to the effects of vibration-induced movement are listed below:

- Unrestrained objects on a shelf that may move, fall, overturn, or collide with each other.
- Objects with loose components that collide with each other, e.g. impact of a heavy canvas against stretcher bars.
- Projections, assemblies, or other object components with existing damage that may concentrate the stress of any applied vibration.
- An object with fragile surface details that moves on a loosely fitted mount or that rubs against its cushioning during shipment (see Vignette 1.).
- Loose packages on a high stack that can fall inside a transport vehicle.
- Loose cargo on a transit vehicle that can bounce repetitively during transport (see Vignettes 2 and 3).
- Multiple objects inside a package, which are not properly separated, that collide with each other (note that this also contributed to the damage in Vignette 3).

Sources and intensities of force

For risk assessment purposes, it can be convenient to group sources of physical force in categories based on incidence and intensity. Four typical force categories are described below. The sources of force in each category appear in approximately decreasing order of severity.

Catastrophic forces (low incidence, high intensity)

These forces have a low rate of occurrence, but they can inflict large-scale damage to large numbers of items if and when they do occur.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

- **Earthquake**-induced ground movement is a source of potentially catastrophic damage in zones of moderate-to-high seismic activity. Note that a substantial portion of earthquake damage results from simple movement (as discussed above) as opposed to forces imposed by an earthquake's motions.
- **War and vandalism** may cause disastrous damage to structures, large numbers of objects, or individual works of art, especially popular or symbolic objects.
- **Shipment disasters** involving major vehicle accidents, e.g. overturning or a rear impact can cause severe damage to any object in transit.
- **Extreme handling hazards** such as accidents, intentional mishandling, and negligence that are not anticipated by typical prediction methods (e.g. probable drop height).
- **Roof collapse** due to snow or water accumulation, which can increase loads beyond structural design limits.
- **Floor collapse** under conditions of excessive load or load concentration (e.g. when moving or installing heavy objects).

Working forces (high incidence, moderate-to-high intensity)

Forces encountered in daily activities with moderate-to-high magnitudes and incidence rates. The force magnitudes are usually predictable. They may affect one, several, or many items at a time.

- **Handling.** Manipulation of objects by manual or mechanical means, during movement, photo shoots, installation, crating, and uncrating.
- **Transit (in-house).** Impact, drops, and load concentrations when moving objects from one location to another inside a museum.
- **Shipment.** Moving packaged items from one venue to another, which includes handling (loading, unloading, cargo transfers) and the vehicle transport phases of shipment.
- **Gravitational loads.** Temporary or permanent distortion of objects as a result of gravity. Crushing or breaking object parts, distortion, and/or compressing object mounts. Distortion and failure of improperly designed pedestals or platforms for large, heavy objects.
- **Construction vibration.** Caused by nearby blasting or construction operations.
- **Excavation.** Structures may be damaged if the structures settle or shift due to lack of support near excavated areas.

Cumulative forces (high incidence, low intensity)

Low-intensity forces with a high (based on collection use rates) or continuous (e.g. gravity) incidence that inflicts ongoing damage to one or many items in a collection.

- **Handling.** Wear and tear caused by handling objects over time, especially objects made of, or which incorporate, poorly adhered, weak, fragile materials.
- **Shipping.** Low-level forces such as vibration inside packaging systems that affect object parts or surfaces.
- **Gravity.** Improperly designed supports that concentrate static loads on objects or their parts leading to distortion or breakage after an extended period of time.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Low-level Forces (variable incidence, low intensity)

These forces may raise concerns and cause annoyance to building occupants, but their direct action may not pose significant risks to objects.

- **Building vibration** from internally generated sources such as occupant activities, mechanical equipment, and nearby road traffic.
- **Construction vibration** from controlled blasting, distant blasting operations, pile driving, reciprocating equipment, and other construction activities.
- **Acoustic sources** that include audible or sub-audible, air-borne vibration, loud music.

A more detailed look at some of the more important sources of force among those mentioned above follows in approximately decreasing order of severity.

Ground motion due to earthquakes

The magnitude of an earthquake is measured on a Richter scale. A Modified Mercalli index is used to relate earthquake intensity to the apparent effects of the ground motion (Table 1). While the acceleration levels are low, earthquakes may involve substantial ground displacement and, therefore, earthquake acceleration levels are not directly comparable to acceleration levels from other sources in terms of damage potential.

Table 1. Description of earthquake effects and approximate relationships between intensity and magnitudes (from Seismic Upgrading Study of the Main Public Library Building San Francisco California for the Asian Art Museum at the Civic Centre, Volume 1 Study Report, September 1992, Rutherford & Chekene Consulting Engineers).

Modified Mercalli intensity scale	Description of effects	Maximum acceleration (g)	Richter magnitude
I	Not felt except by persons under highly favourable circumstances	-	M2 to M2.5
II	Felt by persons at rest, on upper floors, or favourably placed	-	M2.5 to M3.1
III	Felt indoors; hanging objects swing; vibration like the passing of light trucks occurs; might not be recognized as an earthquake	0.003 to 0.007	M3.1 to M3.7
IV	Hanging objects swing; vibration like the passing of heavy trucks, or there is a sensation of a jolt like a heavy ball striking a wall; standing motor cars rock; windows, dishes, and doors rattle; glasses clink; crockery clashes in upper range of IV; wooden walls and frames crack	0.007 to 0.015	M3.7 to M4.3

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

V	Felt outdoors; direction estimated; sleeping persons awakened; liquids become disturbed, some spill; small unstable objects are displaced or upset; doors swing, close, and open; shutters and pictures move; pendulum clocks stop, start, change rate	0.015 to 0.03	M4.3 to M4.9
VI	Felt by all; many are frightened and run outdoors; persons walk unsteadily; windows, dishes, glassware breaks; knickknacks, books, etc. fall off shelves; pictures fall off walls; furniture moves or overturns; weak plaster and masonry D (consult notes at the bottom) crack; small bells (church, school) ring; trees and bushes shake	0.03 to 0.09	M4.9 to M5.5
VII	Difficult to stand; noticed by drivers of motor cars; hanging objects quiver; furniture breaks; damage occurs to masonry Dincluding cracks; weak chimneys break at roofline; plaster, loose bricks, stones, tiles, cornices fall; some cracks appear in masonry C; waves appear on ponds, water turbid with mud; small slides and cave-ins occur along sand or gravel banks; large bells ring	0.07 to 0.22	M5.5 to M6.1
VIII	Steering of motor cars affected; damage occurs to masonry C with partial collapse; some damage occurs to masonry B, but none to masonry A; stucco and stone wall fail; Twisting, fall of chimneys, factory stacks, monuments, towers, and elevated tanks occur; framehouses move on foundations, if not bolted down; loose panel walls are thrown out; changes occur in flow or temperature of springs and wells; cracks appear in the ground and on steep slopes	0.15 to 0.3	M6.1 to M6.7
IX	General panic; masonry D is destroyed; masonry C is heavily damaged, sometimes with complete collapse; masonry B is seriously damaged; general damage occurs to foundations; frame structures shift off of foundations if not bolted to them; frames crack; serious damage occurs to reservoirs; underground pipes break; conspicuous cracks appear in ground; sand and mud ejected in alleviated areas; earthquake fountains and sand craters occur	0.3 to 0.7	M6.7 to M7.3
X	Most masonry and frame structures are destroyed; serious damage occurs to dams, dikes, and embankments; large landslides occur; water is thrown on banks of canals, rivers, lakes, etc.; sand and mud shifted horizontally on beaches and flat land; rails slightly bent	0.45 to 1.5	M7.3 to M7.9
XI	Rails are greatly bent; underground pipelines are completely out of service	0.5 to 3	M7.9 to M8.5
XII	Damage nearly total; large rock masses displaced; lines of sight and level are distorted; objects are thrown into the air	0.5 to 7	M8.5 to M9

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

- Masonry A: good workmanship, mortar and design; reinforced, especially laterally, and bound together by using steel, concrete, etc.; designed to resist lateral forces.
- Masonry B: good workmanship and mortar; reinforced, but not designed in detail to resist lateral forces.
- Masonry C: ordinary workmanship and mortar; no extreme weakness such as failing to tie in corners, but neither reinforced or designed to resist horizontal forces.
- Masonry D: weak materials such as adobe; poor mortar; low standards of workmanship; weak horizontally.

Structural considerations

Museums and museum storage facilities are often housed in buildings that were originally designed for other purposes. Two important structural issues to keep in mind are roof construction and floor-load capacity. Flat roofs without proper drainage may deflect and initiate a cycle that accumulates increasing amounts of water that can load the roof beyond its design limits. A flat roof adjacent to a peaked roof that sheds snow onto it may also be vulnerable to overloading. Floors for some museum applications must be strong enough to support the loads imposed by heavy objects or large collections. Note as well that lifting heavy items with equipment, such as gantry cranes, will concentrate loads onto relatively small areas of the floor. In some cases, it may be possible to shore up the floor from below to enable a heavy item to be lifted and safely moved along a pre-defined path. Wherever there is doubt, seek the services of a structural engineer. This is also a good precaution even if drawings or other specifications are available because these documents may not always describe the structure accurately or "as built."

Probable drop heights for packages

The size and weight of any given item determines how it will be handled. Handling methods, in turn, can be used to predict hazard intensities during shipment. The packaging industry has assigned probable drop heights to package weights and sizes. Table 2 is a typical example. Probable drop height is a reasonable worst case scenario that is infrequent, and unlikely to be exceeded. Most of the drops that occur during shipment will be from much lower heights. Probable drop height estimates are derived from a long history of observations and experience in industry. Other estimates have been obtained from studies involving shipping packages containing electronic recording instruments (Allen 1971).

Table 2. Handling hazards expressed as a probable drop height for different package sizes and weights. Although drop heights will vary according to the distribution network used, they provide a reasonable estimate of risk that is only occasionally attained or exceeded (Brandenburg 1991).

Package Weight (kg)	Greatest Dimension (cm)	Probable Drop (cm)	Form of Drop	Type of Handling
10	120	100	Any side or corner	One man throw
10 – 20	90	90	Any side or corner	One man carry
20 – 45	120	60	Any side or corner	Two men carry
45 – 70	150	50	Any side or corner	Two men carry

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70 – 90	150	45	Any side or corner	Two men carry
90 – 270	180	60	Rotating, either end roll or tip	Mechanical
270 – 1360	Unlimited	45	Rotating, either end roll or tip	Mechanical
1360 +	Unlimited	30	Rotating, either end roll or tip	Mechanical

Handling

Routine handling and accidental drops can easily generate damaging impacts and shock levels. The accelerations that may be expected at various drop heights for different packaging treatments are summarized in Table 3. Many items considered highly fragile, such as unfired clay, will sustain shocks of up to 50 g. Some items that are thought to be highly fragile can sustain even greater shock levels.

Table 3. Approximate shock levels for drops onto a hard surface from various drop heights. The risks to fragile items from typical drop heights and the substantial benefits of some simple packaging treatments are evident.

Drop height cm	Unpackaged metal container g	Wooden box g	Carton g	25 mm Cushioning g	50 mm Cushioning g
120	392	196	131	98	52
110	367	183	122	92	49
90	339	170	113	85	45
60	277	139	92	69	37
15	139	69	46	35	18
5	80	40	27	20	11

Shock and vibration in transport vehicles

If packages are properly tied to the transit vehicle, the shocks generated by vehicle movement are roughly equal to a 15 cm drop. If packages are not tied to the transit vehicle, they may bounce repeatedly resulting in high-impact loads on the packages (see Vignette 3). Another cause of high impact to unrestrained cargo is simply the result of falling off a high stack due to cargo movement during transport. With proper restraint, the highest shock level that can be expected in transit vehicles occurs during the coupling of rail cars and from slack in the rail car couplings.

Vehicle vibration has been studied in detail by military and commercial investigators because all cargo on a transport vehicle will be subjected to vibration (the probability of vibration exposure is 100%) and, unlike handling hazards, vehicle vibration cannot be observed visually. A vibration summary for common modes of transport from Ostrem and Godshall appears in Figure 9. Please note: this information derives from laboratory testing of objects and packaging systems; however, the reference contains information of practical interest to the reader.

Vibration magnitude in most well maintained transport vehicles is low and is generally regarded to be below the damage threshold of most commercial products in the absence of resonance effects. Among common carriers, truck transport generates the highest vibration magnitude and, therefore, has the greater damage potential. Vibration levels in air-ride trucks will be lower than in trucks with conventional suspensions. Because trucks are an integral part of almost all transport scenarios, data on their vibration environments has been used in experiments with models or art objects, such as canvas paintings. Overall, the secondary effects of vibration appear to be one of the most important issues during transport. (Consult the "Control Strategies" section for advice on how to control vibration effectively.)

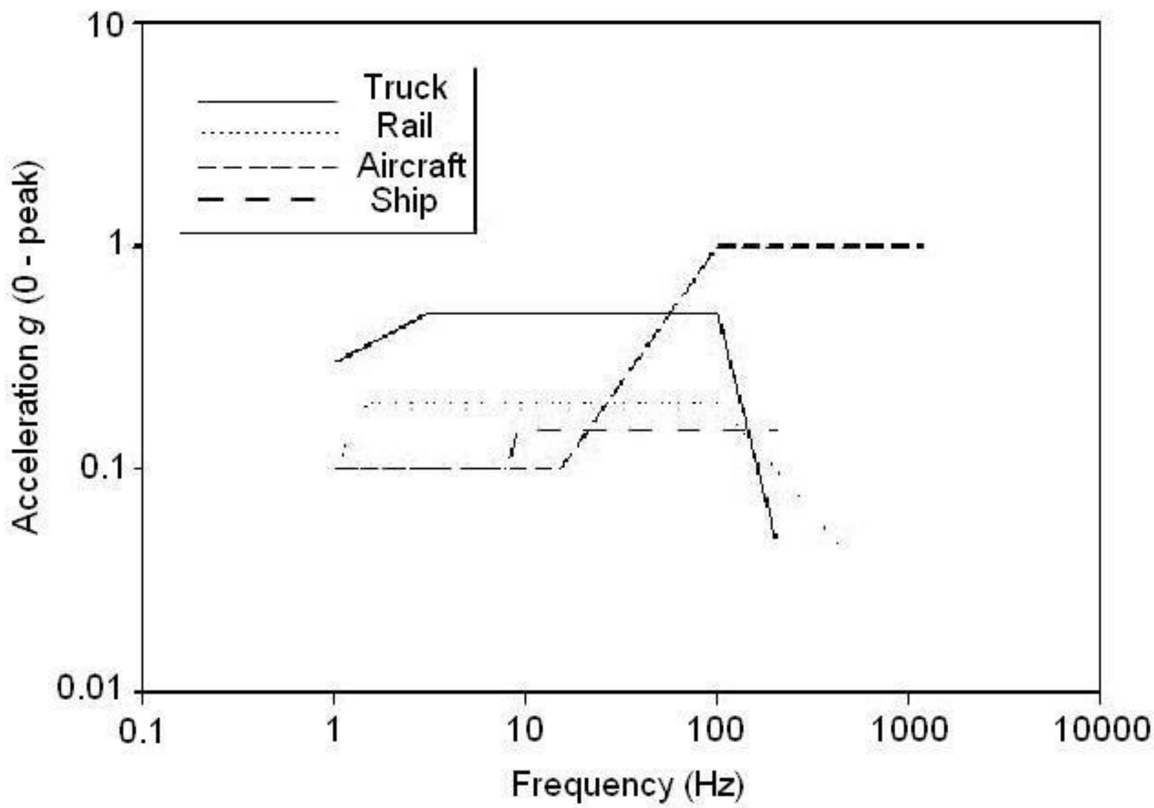

Figure 9. Vibration summary curves for common transport vehicles (Ostrem and Godshall 1979). Note that this summary is an envelope of peak vibration amplitudes at various frequencies. Also, note that only a portion of the vibration enclosed by this envelope will be present at any given time due to the random nature of vehicle vibration.

Gravity

Gravity imposes a force on objects in direct proportion to their mass. This results in a familiar quantity we know as weight (weight = mass × acceleration). Gravitational loads on objects or support materials may be concentrated by geometry.

Distortion of and strain on objects or their parts due to inadequate support may occur quickly, or over longer periods. Lifting large items will concentrate the gravitational loads at the lift points.

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Construction vibration

Investigations have been undertaken to quantify the vibration levels that damage buildings. Construction vibration literature indicates that most construction activity does not generate enough energy to cause structural damage in buildings and, as a result, the focus of almost all the damage investigations has been on blasting operations.

Table 4 contains data on vibration levels that cause three categories of building damage. The data was obtained from investigations involving new and old structures (and their substantial variations in condition, site details, and pre-existing strains). The same source provides data on strain levels (expressed as equivalent particle velocities) induced by building occupant activities, environmental changes, and blasting. This shows some interesting results — specifically that some of the highest strain levels recorded were the result of building occupant activities and daily changes in temperature and humidity. Some additional points concerning blast-related cracking in buildings are outlined below (Dowding 1996):

- Cracks are caused by a variety of construction defects.
- Buildings will contain many cracks, which the occupants may not be aware of, that will increase in size and number each year in the absence of vibration.
- Most of these cracks are cosmetic and are not structurally harmful. (Author's note: Wherever there is concern about the appearance of cracking and there is any doubt about its significance, an expert investigation should be carried out.)
- Slamming doors and passing traffic may vibrate buildings more than noisy blasts or pile driving.
- Humans are more sensitive to vibration than structures.

Table 4. Three levels of observed response of structures to blasting vibrations (Edwards and Northwood [1960]) and the appearance of these effects in 16 damage studies reported as described by Dowding (1996). Particle velocity is often used to describe construction or blasting due to its correlation with the appearance of cosmetic cracking. Note that the particle velocity values represent levels at which the effects have been observed in actual investigations and are not provided here as limits.

Effect	Particle Velocity (mm/s)	Description of effect
Threshold	76	Opening of old cracks and formation of new plaster cracks; dislodging of loose objects (e.g. loose bricks in chimneys)
Minor	114	Superficial, not affecting the strength of the structures (e.g. broken windows, loosened, or falling plaster); hairline cracks in masonry
Major	203	Serious weakening of the structure (e.g. large cracks or shifting of foundations or bearing walls, settlement resulting in distortion or weakening of the superstructure)

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Wherever there is concern about the effects of construction activities, pre-construction crack surveys can help establish a clear connection between any damage that is observed and the forces generated by construction activity. Where naturally occurring crack development is ongoing in the absence of vibration, changes in the rate of crack development may be informative. Detailed information on crack observation and documentation methods is available (Dowding 1996).

Fragility of objects

Having information on object fragility is an essential part of risk assessment. Hazards can then be limited to force levels that are at an acceptable margin below levels that cause damage. Beyond this, there is little advantage in trying to eliminate shipping forces entirely and trying to do is rarely feasible in terms of cost. Because art differs widely in materials, construction, and condition, making accurate fragility assessments is a harder task than it is for commercial products. Investigations into the shock and vibration sensitivity of canvas paintings, plaster, clay pottery, and some glass objects have been carried out. A useful base of knowledge on this subject is emerging. Despite the lack of accurate fragility data for many object types, it is still possible to make reasonable fragility estimates and mitigate hazards in a way that is satisfactory for a chosen method of shipment.

Shock fragility estimation by comparison to commercial categories

The use of commercial fragility information has been helpful for making inferred estimates for some museum objects. Six fragility categories for commercial items with museum objects juxtaposed are illustrated in Table 5. The museum examples shown are the outcome of experience-based estimates and experimental investigations. These observations have shown that many museum objects will be safe inside packages that are designed to limit shocks for worst-case drop hazards to about 50 g or less.

Table 5. Commercial shock fragility categories with examples of fragility ratings for commercial products and some museum objects. The fragility figures are peak accelerations that must not be exceeded, or are the maximum acceleration that the objects can withstand without damage.

Category description	Commercial product examples	Museum object examples	Fragility range (g)
Extremely Fragile	Missile guidance systems, precision-aligned test instruments	Plaster sculpture; 120 kg, hollow plaster test model damaged at 20 g. Other sculpture scenarios may be more fragile	15 to 25
Very Delicate	Mechanically shock-mounted instruments and electronic equipment	Unfired clay (greenware) and fragile glassware	25 to 40

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Delicate	Aircraft accessories, electric typewriters, cash registers, and other electrically powered office equipment	Unfired clay, low-fired clay, plaster, stucco, glassware, ceramics	40 to 60
Moderately Delicate	Television receivers, aircraft accessories	Very weak, damaged, and flaking paint on a 60 x 60 cm painting is dislodged by a corner or edge impact	60 to 85
Moderately Rugged	Laundry equipment, refrigerators, appliances	Uncracked, brittle 60 x 80 cm canvas painting with brittle (low glue content) gesso develops cracks during corner drop	85 to 115
Rugged	Machinery	60 x 80 cm canvas painting (topple, edge drops when equipped with a protective backing board). Small partially adhered canvas paint flakes do not delaminate; tolerated by small boxed collections of pinned insects	115 and up
Very Delicate	Mechanically shock-mounted instruments and electronic equipment	Unfired clay (greenware) and fragile glassware	25 to 40

Object characteristics and sensitivity to forces

The following parameters influence the sensitivity of any given object to force. Knowing this can help anticipate the susceptibility of unusually fragile items or items for which fragility data is not available.

Mass

As an object's mass increases, so does the force that acts on it for any given level of acceleration (Newton's Second Law **F** = ma, where: **F** = Force, **m** = object mass, **a** = acceleration). This explains why small, light, paint flakes may not fly off a canvas at low to moderate levels of shock or vibration because considerable acceleration is needed to overcome even a relatively weak adhesive force that holds a lightweight particle in place.

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Material weakness

Material weakness makes an object highly sensitive to direct handling. Note that material weakness does not always result in a high sensitivity to shock or vibration. Some items, such as pastel paintings, are almost impossible to touch without damaging them, yet the very low mass particles on some older (as opposed to some recently made) works may not be easily dislodged by shock. The shock sensitivity of an object made of weak material will increase with increasing mass. A good example is unfired clay (greenware), which is highly sensitive to both handling forces and shock.

Geometry

As the complexity of an object's geometry increases, so does its susceptibility to force. Projections often create sites where forces (and stress) can multiply in object materials.

Flexibility

Flexibility in objects can be considered a structural weakness. Wherever flexibility exists, there is a tendency to vibrate. This makes the object susceptible to the force multiplying effects of resonance or to damage when moving parts collide. The control of obvious vibration tendencies by gentle but firm restraint is an important part of avoiding shipping damage to fragile objects. Good mount-making practice will also help avoid any vibration tendencies (Figure 10).

Vibration susceptibility

Vibration fragility ratings for commercial products specify damage thresholds in terms of frequency and amplitude. Another method of vibration susceptibility used in the packaging industry involves determining the first few resonant frequencies of an object in the transport frequency range of 1 to 200 Hz. Vibration tendencies in this range may be of concern due to possible resonance effects that can amplify low-level transit vibration to damaging levels. The first few frequencies of the object are usually of greatest interest because lower frequencies involve the largest displacements and strains.

Examples of object susceptibility to handling, shock, and vibration

The following examples indicate the force susceptibility of some different object types. Because materials, compositions, and configurations of actual objects vary widely, these are considered general examples.

High sensitivity to manual handling due to material weakness

Objects made from lightweight, weak materials in any mass range are susceptible to forces due to gravity (point loads, improper support) and direct handling:

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- Pastel paintings (handling, abrasion).
- Paintings with fragile surfaces (handling abrasion).

Moderate handling sensitivity, low shock, and vibration sensitivity

Strong, low-mass materials and assemblies:

- Small pinned insect display

High handling sensitivity with shock susceptibility

Where material weakness exists or if moderately strong materials are stressed by mass, geometric complexity or a combination of both:

- Large pinned insect displays
- Unfired clay, terracotta, plaster, and stucco (handling, abrasion, shock).
- Some ethnographic materials (handling, abrasion, shock, and vibration).
- Paintings with cracked fragile and reasonably thick (massive) paint layers.
- Some contemporary artwork, kinetic artwork.

High sensitivity to shock and vibration

Mass and geometric complexity combine to make these objects fragile:

- Assembled skeletons, composite objects.
- Clocks with unrestrained mechanical components.
- Contemporary art (e.g. fragile glass Terella, see Figure 16) with inaccessible, internal components that vibrate at low frequency).
- Canvas paintings (shock resulting in stretcher bar deformation, low-frequency vibration that may lead to secondary effects such as abrasion or collision).

High sensitivity to mechanical lifting and load concentration, high shock (primarily), and vibration sensitivity

This result is due to mass, geometry, and material properties: mass augments the effects of forces on compact forms of moderate to strong materials. Geometry and notch sensitivity in brittle materials further increases the sensitivity of strong materials to direct force, shock, and vibration:

- Large paintings (mass-driven stretcher bar deformation, collision of canvas with stretcher bars).
- Sculpture (high mass, brittle, notch-sensitive materials, projections).

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Control strategies

An effective preservation strategy involves setting up control measures to counteract the action of potentially damaging forces. The general strategies for basic, medium, and high-level control strategies are summarized below. They also incorporate priority issues for force control, which are also listed below in approximately decreasing order:

1. Earthquake (stabilization of buildings, hardware, and objects in high-risk areas). See Vignette 4.
2. Structural details (floors, roofs, artifact supports, hardware).
3. Handling (crating, uncrating, moving in-house, isolation from public).
4. Shipment (shipping hazards).
5. Long-term wear (cumulative forces in storage or from repeated handling).

Control of damaging force levels is possible by a variety of individual features at three different levels of implementation: **buildings, hardware,** and **procedures**. Building level controls are the most expensive to achieve. Large institutions will incorporate many of their control features here. Effective control is also possible at lower cost at the hardware and procedural levels. For any level of implementation, individual features will enable a sequence of control stages to **Avoid, Block, Detect**, and **Respond** to the action of forces agent. Each stage in the control sequence comes into play whenever a preceding one is either not feasible, not possible, or fails. This establishes an effective line of defense against physical forces or other agents of deterioration. A general summary of control features by level of implementation appears below. Table 6 lists features by scale under the various four control stage headings.

1. Basic (control of major risks)

Buildings

- Earthquake-resistant buildings in zones of seismic risk.
- Consider all non-structural hazards (including monumental items such as sculpture) in seismic zones and secure as necessary.
- Ensure seismic stability in the design of pedestals, hangers, and mounts for large objects in seismic risk zones.
- Good, structurally sound buildings with adequate floor strength. Ensure that the use of existing buildings is appropriate for museum application.
- Attention to basic building design features (halls, doorways) to promote good access.
- Avoid flat roofs.
- Re-locate vibration-sensitive equipment to ground floors, near load-bearing walls, or near support columns on upper floors to avoid vibration problems.

Hardware

- Rigid shelving and stabilization of all objects in seismic areas.
- Provide moving equipment (e.g. dollies, carts, lifts, slings) for prompt evacuation of objects where necessary.
- Basic isolation between the public and objects on display (cases, barriers).
- Specialized packaging for highly fragile or vulnerable items.

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- Select appropriate storage surfaces and mounts for specific items.
- Use specially designed (high mass) tables or vibration isolators for sensitive equipment.

Procedures

- Use specialized art handler's carriers for highly valuable or fragile items, appropriately crated.
- Primary packaging on a basic level to protect selected fragile items from puncture, dent, scratches, abrasion, and minor impact. (Primary protection refers to a basic packaging treatment that enables a fragile item to be handled easily. Protecting the item during shipment normally requires additional packaging.)
- Identify and protect highly susceptible items from routine handling while in storage, during display, and in transit.
- Secure all objects or packages in vehicles during transport.
- Provide staff training on handling fragile museum objects.
- Provide staff training in machine operation and on handling objects (rigging) up to 2,300 kg or hire experienced handlers (riggers) for loads greater than 2,300 kg.
- Acquire training and expertise on packaging requirements for vulnerable items.
- Provide security staff in exhibition areas.
- Ensure that object surfaces are clean before packing to avoid abrasion or forcing dirt into object surfaces.

2. Medium (control for moderate-to-high intensity forces)

Buildings

- Provide specialized loading bays and handling equipment such as smooth lifts, load levelers, smooth soft floor, and wall finishes.
- Provide impact-absorbing door perimeters.

Hardware

- Provide gantry cranes for moving or re-orienting heavy objects.
- Ensure seismic stabilization of small-to-medium-size objects.
- Transit framework and modular systems for transport and handling large objects that travel. This may take the form of incorporated features that enable large, heavy items to be easily moved during a multi-venue exhibition.
- Primary packaging with the basic benefits that it provides (as discussed above).
- Basic packaging — good crates with adequate (typically at least 50 mm) thickness of cushioning material.
- Well-designed mounts for storage, transport, and display.

Procedures

- Staff training in object susceptibility, object handling, mountmaking, and packaging.
- High-level isolation of fragile items from the public in display areas (effective barriers, cases, alarms).

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3. High (control of All Perceived Risks of This Agent)

Requires all of the above described control strategies plus implementation of collection-specific needs dictated by a comprehensive collection survey. Rank order and implementation of relevant building hardware and procedural features for collection.

Preventive conservation framework

There are many ways to implement an effective control strategy against forces. Table 6 is an excerpt from the **Framework for Preservation of Museum Collections**, which identifies nine additional agents of deterioration and the control features for each agent. Many control features for forces are found in the **Block** control stage.

Table 6. Preservation framework for control of forces. Note that most force controls are implemented under the Block stage.

Hardware	Buildings	Transit	Procedures
AVOID • Avoid unstable shelves and cabinets	AVOID • Avoid areas of high seismic risk • Avoid building on soft, loose soils • Ensure adequate floor strength • Smooth, soft interior wall finishes • Adequate access	AVOID • Avoid handles at incorrect heights • Use well-maintained air-ride trucks • Provide lifts and dollies to move objects safely • Plan object movements	AVOID • Avoid unreliable art handlers, common carriers, poorly maintained fleets • Consider modular packaging designs or lifting provisions forlarge objects and for items that are frequently moved or are intravelling exhibitions • Maintain space between collections
BLOCK • Block and distribute forces with cradles and fitted supports made of inert padding • Block forces with primary packaging • Ensure adequate shelf space	BLOCK • Construct earthquake-resistant buildings • Ensure adequate space for collections storage or display	BLOCK • Separate items from each other • Block forces with primary packaging • Block forces with packing cases and cushioning material • Brace, restrain, or disassemble vibration-prone components	BLOCK • Train staff on techniques for supporting objects • Train staff on techniques for packing objects • Train staff in techniques for handling objects • Train staff in rigging techniques for loads up to 2,000 kg

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• Separate objects from each other and from the public • Provide discrete cradles and supports made of inert padding for items on display • Immobilize and secure objects especially in areas of high seismic risk		• Isolate fragile surfaces from package component movement	• Hire pro-fessional riggers if it is necessary to reorient heavy loads for transport • Hire professional riggers for loads greater than 2,000 kg
DETECT • n/a	DETECT • Adequate space for inspection of objects	DETECT • Detect forces using tipping indicators, shock detectors, and data loggers • Use items above to verify package performance	DETECT • Record new damage • Take good photos
RESPOND • Isolators for objects	RESPOND • Seismic isolation of buildings	RESPOND • Redesign poorly performing packages	RESPOND • Obtain package design expertise

Protecting Fragile Objects during Shipment

After seismic forces and forces affecting structures, in-house handling and shipment are the usual highest commonly encountered level of force magnitudes that museum objects encounter. Staff training, planning, building, and hardware features all contribute to reducing the risk of damage from these sources. A general overview of important issues related to handling and shipment follows.

Avoid fundamental deficiencies

Serious damage to packaged items can result from fundamental oversights. Simple matters such as a container's durability, accounting for how packaged objects may move and interact with each other, and securing packages to the transport vehicle can make a big difference.

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Cargo restraint

Unrestrained, stacked cargo in vehicles can fall and experience higher than anticipated drops. In one example of severe damage, unrestrained cargo simply slid off a truck (see Vignette 2).

Unrestrained cargo can also bounce, shift, and collide repetitively resulting in high-impact forces (see Vignette 3). Content movement inside unrestrained packages may also result in damage (another cause of the damage described in Vignette 3).

Avoid unnecessary forces

Transit forces are impossible to avoid, but carrier choices can make a big difference in the forces that act on packages during shipment. One shipping study comparing an art handler shipment with common carriers did not record a single shock event for the art handler shipment (despite a very low recorder activation threshold of 5 g). When shipping numerous items, high-quality transport and handling can save money, by reducing packing and crating requirements (consult Figure 10). Crate design features can also help reduce handling hazards. Such features include handles at appropriate positions (height) to help minimize the height from which a package may be accidentally dropped; and clearance provided at the base of cases to enable the use of pallet jacks (helps avoid unnecessary strain and possible deformation of large containers and strain on their contents. Lightweight packages, that are transportable inside an institution, can also protect objects until they reach their ultimate exhibition location.

Assess hazards for your distribution network

Each distribution network carries its own profile of risk. It is reasonable to expect fewer and less severe impacts during art handler shipments. Investigations using packages containing data loggers have been able to show the difference. Common carrier shipments will usually call for greater package durability and better cushioning than do art handler shipments. Tabulated data from commercial sources on probable drop heights for different package weights or size are available (consult Table 2). The tabulated values indicate the maximum probable drops that might be expected; however, note that these are infrequent events. Less than 5% of drops will ever exceed these values (according to the Institute of Packaging Professionals [IoPP]).

Decrease the objects susceptibility to force

Commercial products are usually redesigned if they fail to meet basic durability requirements in order to reduce packaging costs. Identifying and addressing potential weaknesses in the object will protect it outside the shipping crate. Examples might include disassembling fragile vibration-prone components, and restraining vibration-prone items, the latter being common practice in commercial shipments. Treating artwork to increase its durability and adding features such as protective backings for paintings that "stiffen" the canvas painting structure (Figure 11 and 12) will decrease packaging performance requirements. A stretcher lining treatment is a lightweight alternative for larger paintings (Figure 12).

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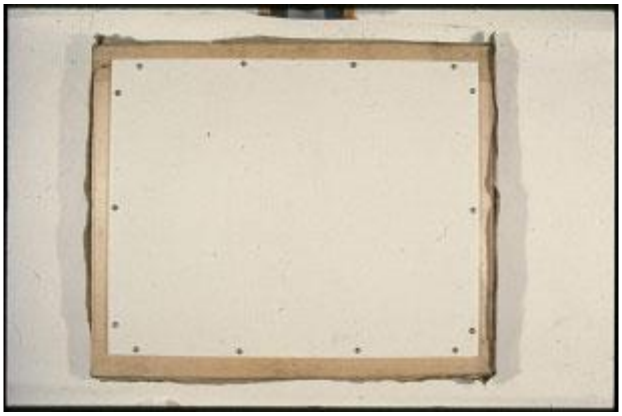

Figure 11. A simple fluted plastic backing on a test canvas painting. This treatment can reinforce the flexible stretcher bar assembly and lower the painting's sensitivity to shock (consult Table 7).

Figure 12. Applying a stretcher lining made of polyester sail cloth (consult Booth 1989) to a large canvas test painting can reduce its susceptibility to vibration, while adding little weight to the painting. The treatment is quite effective (consult Table 8).

Table 7. The fluted plastic backing board in Figure 11 almost doubles the durability of the canvas painting against some shock hazards. Shock levels resulting in damage are summarized here.

Backing board	Corner Drop (g)	Topple (g)	Edge Drop (g)	Flat Drop (g)
No	65	80	100	100

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Yes	190	Topple from 90° without damage	100 (estimated)	200

Table 8. A comparison of several treatments for controlling the vibration sensitivity of a 120 x 150 cm test canvas painting.

Condition	Resonant Frequency (Hz)	Displacement (centre of canvas for a constant vibration amplitude) (mm)
Painting	5	100
Masonite backing board	16	18
Fluted plastic (with centre attachment)	18	15
Fabric lining (illustrated above)	20	3
Aluminum honeycomb	24	8

Provide primary protection

Fragile objects benefit from supports that enable them to be handled and transported easily (Figure 13). Lightweight mounts and enclosures protect against direct handling forces and direct application of force that may lead to scratches, dents, punctures, and abrasion. Fabricating custom supports can be time consuming, but the supports offer long-term protection if made from archival-quality materials. In some situations, the primary packaging may be used alone for local transport, with careful handling, or packed and cushioned as larger units in larger containers for longer travel distances or multiple venue exhibitions. Finally, a primary packaging system can help transfer the movement away from fragile object surfaces (e.g. a firm-fitting mount that is supported on flexible cushions should avoid movement along the object–mount interface).

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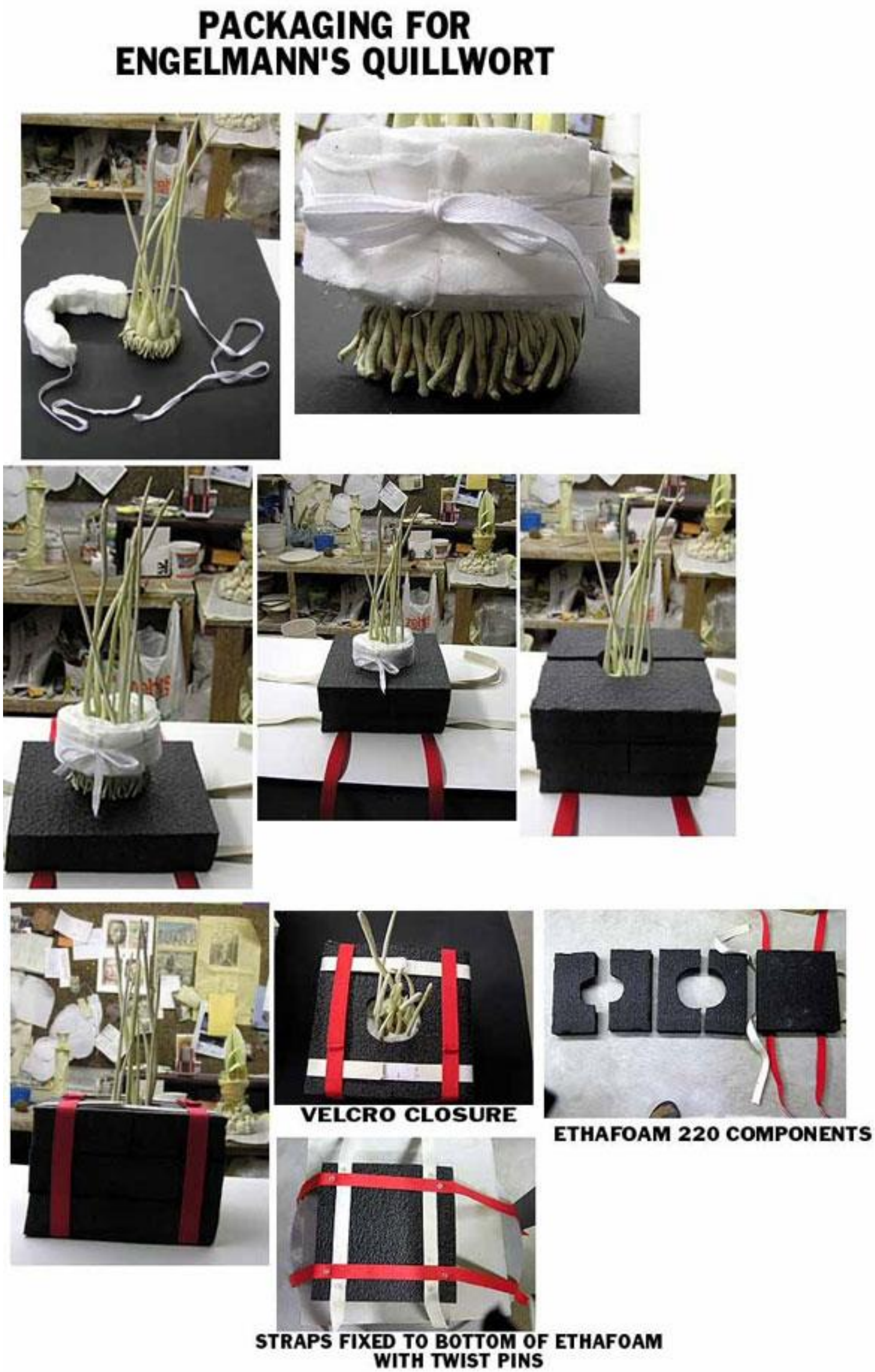

Figure 13. Primary packaging for a collection of 50 fragile porcelain sculptures of endangered plants. The mounts provide long-term storage and enable the exhibit to be quickly and safely transported to local destinations. These basic packaging units can be grouped together, cushioned, and crated for longer shipments or traveling exhibitions. Artwork by Julie Aubin.

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Provide basic cushioning

When a cushioned object is dropped, it will gradually sink into the cushioning material on impact. The object decelerates gradually, which limits the forces on the object to levels it can sustain without damage. A successful outcome requires an appropriate material choice to enable the object to deflect into the cushioning material without bottoming out and striking the inside of the packing case. A 50-mm thickness of almost any cushioning material applied to all sides of an object (weighing 75 kg or less) can go a long way to ensuring its safe shipment. Bubble pack is the least labour-intensive material to use for small lightweight items. Foams, such as polyurethane and polyethylene, also have excellent cushioning properties. Loose fill materials may be used, but be aware that objects cushioned in this material may travel toward the interior surfaces of the container and there may not be any cushion material present if and when it is needed (Figure 14).

Figure 14. Reproduction glasses made of soda lime glass. Individual boxes containing loosely bubble-wrapped glasses moved in the peanut packaging material and collided, resulting in damage to the pieces.

Use cushion design methods and data

Industry provides detailed performance data for most cushioning materials and a step-by-step procedure for designing protective cushioning. The falling clay pot demonstration illustrates how well cushioning materials can perform if properly selected (Figure 15). Cushioning data is published by material manufacturers and other sources in the form of dynamic cushioning curves, which are easy to interpret after a bit of practice. User-friendly design tools based on these curves have been developed to simplify

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the design process while eliminating the need to interpret graphical data, compare different materials, and perform repetitive calculations.

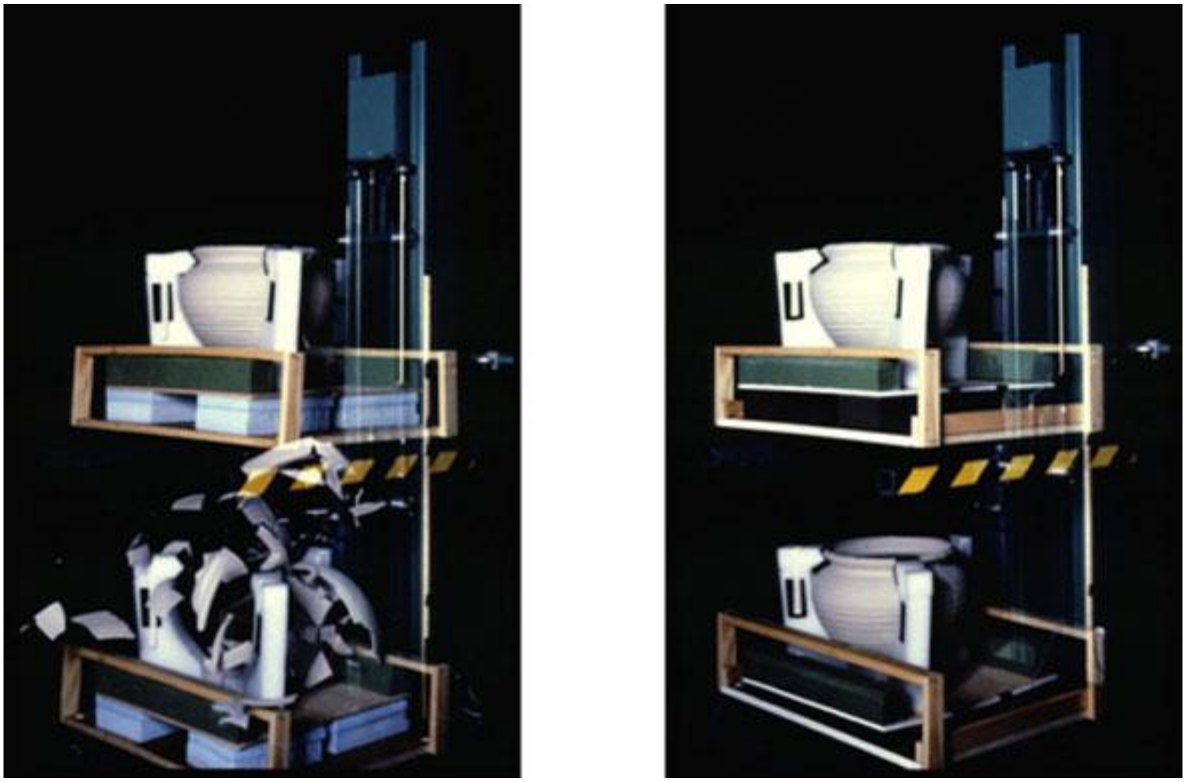

Figure 15. An unfired clay pot falls from a height of 75 cm onto a steel plate.
a) The polyethylene foam support and blue polystyrene pads (cushioning) provide some protection, but not enough for this highly fragile item.
b) Cushion performance data indicates that a set of ether type — polyurethane (24 kg/m^3 density) pads cut to the same size and thickness as the four polystyrene pads shown — will limit shock to less than 40 g. This is enough to protect the pot against repeated 75 cm drops (note the deflection of the pads on impact). Cushioning works by giving the pot more time to come to a stop on impact. This limits the impact forces to a level that an object can sustain without damage.

Consider dynamics of the packaging system

All package components work together to protect fragile items. The shipping container is the first line of defense against punctures, dents, and abrasion. Treatment of the object's surface and how the object is supported/restrained on a cushioning material inside a package also plays an important role in the overall effectiveness of the packaging system. A key requirement for cushioning against shock is to ensure that that the object can sink into the cushion material on impact. The cushioned object must be able to move freely while avoiding excessive looseness. Care should be taken to ensure that projections are not strained as the object moves or deflects into the cushioning material and that fragile surface finishes will not be abraded. Object mounts or fixtures can transfer the movement away from fragile surfaces and projections.

Vibration control measures

There are three ways of controlling vibration hazards during shipment:

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1. Source reduction such as choosing air-ride vehicles and well-maintained fleets.
2. Vibration response of the object altered, e.g. by providing gentle restraint of vibration-prone assemblies and disassembly.
3. Vibration isolation, e.g. by designing cushioning systems to isolate resonant frequencies of objects.

The choice of air-ride vehicles over those with conventional suspension systems will reduce the amount of transport shock and vibration that packages will receive. The painting treatments in Figure 11 and Figure 12 are a form of restraint. Direct restraint of vibration-prone items may be possible for other objects. Disassembly may also be an option in some cases. A cushioning system designed for shock isolation can also provide vibration isolation. A key requirement for achieving this outcome is that the cushioning system has more flexibility than the cushioned item it protects. See Figure 16 for an interesting example involving an inaccessible, flexible component.

Double crating

Double crating can simplify packaging for items with irregular shapes or fragile surfaces (Figure 17). The procedure involves fitting the object firmly onto a transit mount or inner crate that can gently restrain it in all directions and that has simple flat exterior surfaces. Protective cushions can then be easily applied to the inner box (or assembly), which then fits into the shipping crate. Many package designs for highly fragile items have been designed this way and all have performed very well.

Figure 17. An example of a double case system. A case such as this can be designed once and used for different applications provided that the content weight does not change substantially. The only requirement for packing in this case is to ensure that all contents are firmly restrained inside the inner container.

Evaluate overall package performance

A packaging system should be easy to use and should also perform as expected. Packages for multiple venue exhibitions benefit from simple designs with clearly marked removable components that are easy for third parties to uncrate and repack. The package should be easy to open and close without applying force to the contents and without binding the cushioned object inside and restricting its movement. A basic evaluation of crate performance is possible without elaborate instrumentation by simply dropping a crate with simulated contents onto a hard floor using a safe release mechanism (ASTM 2001). Monitors can also evaluate the effectiveness of a cushioning system using simulated (by weight and size) package contents. These monitors may range from inexpensive resettable shock indicators costing a few dollars each to electronic data loggers, which can record shock pulse information and display the results through computer software.

Vignettes

Vignette 1. Venus blue (fragile surface damaged in transit)

Figure 18. Damage to a fragile paint surface that was in contact with cushions during transit.

A hollow plaster figure with a powdery paint surface was packed inside a very well-made shipping container that was transported by an art handler. While this treatment is enough to guarantee success in most cases, the object arrived at the exhibition with substantial surface impressions and could not be displayed. The cushioning method that was used involved floating the object directly on polyethylene foam pads that were covered with a Teflon sheet, which was used to minimize abrasion. Movement between the object and the Teflon sheet and load concentration caused impressions in the pigment. This might have been avoided by fitting the sculpture into a negative mount and floating this combination on pads to eliminate any movement of the object and minimize the load on its fragile surface. An approach such as this was successful for protecting hollow plaster sculptures with fragile surfaces (Marcon 1999). Fortunately, in this case it was possible to eliminate the surface impressions on the **Venus Blue** with a conservation treatment.

Vignette 2. 7.5 million-year-old dinosaur specimen smashed in transit

A transport truck backing down a inclined ramp at a museum had its back doors open. Inside the trailer was a dinosaur fossil that was recently restored at a cost of $250,000. The crate slid out of the truck when the brakes were suddenly applied. It fell onto the concrete ramp, smashing the fossil to pieces. The package, while suitable for most routine handling, did not provide adequate cushioning for a drop from tailgate height. Damage would have been avoided if the package had been securely tied to the transport vehicle or if the package had been designed for a worst case drop from tailgate height.

Vignette 3. Furniture shipping damage (Martha Sturdy, Vancouver, British Columbia)

A Vancouver-based furniture designer shipped acrylic resin samples to a New York trade show inside a very large shipping container. The substantial resin pieces were 50 mm thick and arrived at the destination in pieces. Subsequent investigation revealed that the large shipping container was not tied to the transit vehicle. There is evidence that it moved repeatedly during shipment. This movement, combined with impact between relatively heavy contents that were individually wrapped in thin layers of bubble pack, was the cause of damage. An interesting video documentary on this case is available from the Canadian Broadcasting Corporation (CBC).

Vignette 4. Seismic resilience for artwork and antiquities

(written by Jay Lewis, Terra Firm Earthquake Preparedness)

Many of the world's museums and art galleries are located in large urban areas with the potential for strong earthquakes. The extensive collections of artwork and antiquities can be damaged or lost due to falling, collision with other objects, loss of environmental control systems, water damage, or fire. Most of this risk is controllable by using engineering-based, seismic risk-mitigation techniques.

Earthquake forces

During an earthquake, ground motion may be horizontal in more than one direction as well as vertical. An art object, which is not attached to a building, through inertia, will attempt to stay where it is located as the building moves with the ground. This results in the artwork toppling, sliding, or falling with the resulting damage when it strikes the building or other objects. The seismic forces are also acting on the building, which can trigger falling ceiling systems and structural elements, broken water lines, and fire ignited by failing electrical and fuel systems.

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Options for seismic risk mitigation

There are a number of options for mitigating the impact of an earthquake on artwork and antiquities. These can be grouped into the six "Rs" of seismic risk mitigation in order of impact and cost.

Remove. If the object is not an essential display element, it can be removed from its location and stored away, traded, or sold.

Relocate. There may be safer places within the building for a particular object. Threats in a particular location might be due to another piece of artwork at risk of toppling or a large overhead water pipe. By relocating items within the facility, risk can often be reduced at little cost.

Replace. If there is a decision to be made between a tall and thin item balanced on a thin point and a low and broad item, the latter is the best seismic choice. This is not a choice the curator often has, but, in general, fragile items present more risk that durable ones. Substitution might be a solution, all other factors being equal.

Reinforce. Without affecting the artistic value of the work, some things can be reinforced to be more durable. This can allow the work to resist seismic forces without significant damage.

Reduce. By reducing the seismic forces acting on the artwork, the risk is reduced. This can be accomplished by damping and base isolation. With damping, the forces are partially lowered using energy-absorbing devices so that other mitigation measures are reduced or avoided. By isolating the base, the object is virtually disconnected from the building. In some cases, the entire building is isolated. This approach uses rubber or roller bearings to do the job. Relatively high cost can be an issue if choosing isolation.

Restrain. The last on the list is to restrain an object so that it moves with the building and cannot topple, slide, or fall. This can be done by confining or fastening the object. Confining may be preferable because it does not involve penetrating the work. On the other hand, restraint features can have significant visual impact depending on the design. Restraint has been associated with the conservator's profession for a very long time. Items such as conservation wax, tapes, and specialized display cases are commonly used. Other techniques and products are being introduced to the market on a regular basis.

Engineered solutions

As the prices of artwork and antiquities rise and the liability associated with health and safety issues in public places increases, effective seismic risk mitigation becomes an important element in the curator's job. Because the procedures are complex and demonstrating due diligence is required, the conservator will increasingly consult with a structural engineer for standard and custom solutions and details. Each facility should conduct a preliminary seismic risk assessment of its collection using a commonly accepted procedure such as found in the Canadian Standards Association's (CSA) S832 "Seismic Risk Reduction of Operational and Functional Components (OFCs) of Buildings" (Canadian Standards Association 2006). The CSA also originated the six "Rs" approach to seismic risk mitigation paraphrased above. A prioritized list has been established for establishing a mitigation plan and developing annual budgets for the work. This process establishes a clear due diligence path and reduces risk quickly, at the least cost. Maintaining the mitigation systems, once installed, is an ongoing effort, which requires regular attention and funding.

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When choosing a mitigation system, it is important to clearly identify the objectives of the work in advance. This includes identifying limitations on attachments to the item (such as drilling holes), aesthetic or visual quality impacts, and performance objectives (such as life safety, protection of the asset, or both). Having these parameters clearly identified ensures that the design professional pursues solutions that are appropriate for the circumstances. No museum or gallery in an earthquake zone should be without a comprehensive seismic risk mitigation program.

References

1. Agbabian, M.S., et al. **Evaluation of Seismic Mitigation Measures for Art Objects**. GCI Scientific Program Report. Los Angeles, CA: J. Paul Getty Institute, 1990.
2. American Society for Testing and Materials. **Annual Book of ASTM Standards, Volume 15.09**. Philadelphia, PA: ASTM, 2001. (Detailed drawings for a safe release apparatus are available from ASTM, 1916 Race Street, Philadelphia, PA 19103. Request Adjunct Nº 12-409970-00.)
3. Booth, P. "Stretcher Design: Problems and Solutions." **The Conservator** 13 (1989), pp. 31–40.
4. Canadian Broadcasting Corporation (CBC). "Tempest in a Packing Crate." Aired on June 22, 1997 on "CBC Venture." Toronto, ON: CBC Visual Resources Centre, 1977.
5. Canadian Standards Association. **Seismic Risk Reduction of Operational and Functional Components (OFCs) of Buildings**. CSA S832. 2006. Canadian Standards Association.
6. Castellini P., et al. "Non Invasive Measurements of Damage of Frescoe Paintings and Icons by Laser Scanning Vibrometer: Experimental Results on Artificial Samples Using Different Types of Structural Exciters." Ancona, Italy: Dipartemento di Meccanica, Universita di Ancona. Vol. 4, Nº 12, 6th World Conference on NDT and Microanalysis in Diagnostics and Conservation of Cultural and Environmental Heritage, Rome, May 1999.
7. Dowding, C. **Construction Vibrations**. 1996. ISBN 0-99644313-1-9.
8. Harris, C.M. **Shock and Vibration Handbook**. 3rd edition. New York, NY: McGraw-Hill Publishing Co., 1988, p. 44-23, Figure 44-20.
9. Marcon P., et al. "Packing and Transport of Hollow Plaster Sculpture." pp. 77–82 in **ICOM Committee for Conservation 12th Triennial meeting Lyon, 29 August – 3 September, 1999: Preprints. Vol. 1**. London, UK: James & James, 1999.
10. Michalski, S. "Paintings – Their Response to Temperature, Relative Humidity, Shock and Vibration." pp. 223–248 in **Art in Transit, Studies in the Transport of Paintings** (edited by M.F. Mecklenburg). Washington, DC: National Gallery of Art, 1991.
11. Michalski S., and P. Marcon. "Mechanical Risks to Large Paintings such as **Guernica** during Transit." pp. 87–98 in **El Guernica y los problemas eticos y technicos de la manipulation de obras de arte**. Santander, Spain: Fundacion Marcelino Botin, 2002.
12. Northwood, T.D. "Isolation of Buildings from Ground Motion." pp. 87–102 in **Proceedings of the Isolation of Mechanical Vibration, Impact and Noise Colloquium.** Presented at the American Society of Mechanical Engineers (ASME) Design and Engineering Conference, Cincinnati, OH. New York, NY: ASME, United Engineering Centre, 1973.
13. Packing and Crating Information Network. **Technical Drawing Handbook of Packing and Crating Methods**. Packing and Crating Information Network.
14. Stagg, M.S., et al. **Effects of Repeated Blasting on a Wood Frame House**. Report of Investigations 8896. Washington, DC: U.S. Bureau of Mines, 1984.
15. U.S. Department of Defense. **Military Standardization Handbook, Package Cushioning Design**. MIL-HDBK-304B. Washington, DC: U.S. Department of Defense, 1978.
16. Ungar, E.E. **Vibration Criteria for Sensitive Equipment**. pp. 737–742 in **Proceedings of the Inter-Noise Conference, Toronto, Ontario, Canada, 1992. Vol. 1.**

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

17. USDA Forest Service. **Wood Crate Design Manual**. Agricultural Handbook Nº 252, February 1964.

Key readings

1. Allen, D.C. "Maximum Drops Experienced by Packages in Transit." See Symposium on Shock Environment of Packages in Transit. **Journal of the Society of Environmental Engineers** (1971), pp. 21–28.
2. Brandenburg, R.K., and J. June-Ling Lee. **Fundamentals of Packaging Dynamics**. 4th edition. Michigan State University, School of Packaging. Skaneateles, NY: L.A.B., 1991.
3. Mecklenburg. M.F., ed. **Art In Transit, Studies in the Transport of Paintings**. Preprints for the International Conference on the Packing and Transportation of Paintings. Washington, DC: National Gallery of Art, 1991, pp. 93–106 ("A Circular Slide Rule for Protective Package Design" by P. Marcon) and pp. 121–132 ("Shock, Vibration, and the Shipping Environment" by P. Marcon).
4. Ostrem, F.E., and W.D. Godshall. **An Assessment of the Common Carrier Shipping Environment**. General Technical Report, Forest Products Laboratory, FPL 22, USDA. Madison, WI: U.S. Department of Agriculture, 1979.

Thanks to the Centro Nacional de Conservación y Restauración in Chile, the Canadian Conservation Institute's web resource Agents of deterioration, translated into Spanish by ICCROM, is now available free of charge. Intended for curators and conservators, the resource identifies 10 primary threats specific to heritage environments.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Thieves and vandals

David Tremain

Introduction

Security is an important and necessary part of any cultural institution's risk management program to adequately protect its assets. Every year millions of dollars are lost due to the theft of objects from museums, art galleries, libraries, archives, and places of worship. Some of these incidents are premeditated; others are simply "crimes of opportunity." Most could have been prevented had there been an effective security program with good controls in place. Another ongoing problem is wilful damage caused by vandalism and graffiti to artworks, historic sites, and buildings.

This section will introduce security risk management based mainly on concepts developed by the Royal Canadian Mounted Police (RCMP) and the Government of Canada Security Policy (GSP). While they may vary from those used in preservation, they are well established in the field of security and would be recognized by any security officer working in a museum. The first concept is Threat and Risk Assessment (TRA) that will help you determine new security measures required (RCMP 2000). For assessing risk, security measures in place must also be taken into account. These measures are commonly grouped around the concept of **Protect**, **Detect**, and **Response** (RCMP 2004). **Protect** includes the **Avoid** (**Deter**) and **Block** that are used in other sections of the resource . An additional section on **Recover** has been added even though it is not generally included in the standard safeguard approach. Zoning is frequently used in security where a building is organized into different defensible spaces: from Public Zone to High Security Zone (RCMP 2005). Each zone will have different levels of **Protect**, **Detect**, and **Response** according to the vulnerability of the assets and the access required. For reasons of practicality, the Security Zone concept has been incorporated in the section **Protect**.

Threat and risk assessment (TRA)

Also referred to simply as the Risk Assessment, this assessment is composed of four steps: identify the asset; identify the threats; identify the risks; and recommend security measures. This approach is similar to any generic risk assessment approach.

1. **Identify the asset: The collection**

   Ideally, everything that belongs to a collection should have the best level of protection, but in the real world that is often not the case. The most important or valuable items in the collection should be given the greatest attention. Global vulnerability of the collection can be assessed; however, for optimal performance, it is better to identify which objects or parts of the collection are more vulnerable to thieves and vandals. Some of these items may also be small and, consequently, easily portable, which, if not properly protected, will be attractive items to thieves because of their high resale value, ease of trading on the black market, or because it is the missing item to complete a set. Other items may be controversial — a religious icon or an item having some other significance — or the theft may be attractive just to prove that it can be done.

2. **Identify the threats**

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

> Once you know what it is you want to protect, you will then need to determine what it is you want to protect your assets from (the threat). Identify the exposure of the asset(s) for each identified threat.

Threats affecting an institution's security

There are two primary threats that can affect an institution's security: theft and vandalism.

Theft

Theft is the opportunistic, willful, or premeditated illegal removal of an asset. Most thefts from museums tend to be isolated and not done by professionals, where, on the spur of the moment, the thief — a visitor, a member of a school party, someone who is mentally unstable, or has a grudge against the museum — seizes the opportunity to steal something that is readily available or unprotected. The loss of many of these items, particularly those of lesser importance, tends not to be well publicized. However, the media has popularized the more spectacular international cases, such as the theft of **The Scream** and **Madonna** in Oslo, Norway, in 2004. In Canada in early September 1972, the Montreal Museum of Fine Art disabled its alarm system in order to carry out roof repairs. On Labour Day, armed thieves seized on this lapse in security, entered the museum through a skylight, tied up the security guards, and stole 17 paintings from the museum's European collection. One painting was Rembrandt's **Landscape with Cottages**. Even today, this is still considered to be the most significant Canadian art crime and the second most valuable North American art crime.

Unfortunately, there is very little data publicly available in Canada to indicate just how widespread a problem theft in museums really is. Most thefts from museums and galleries in recent years in Canada have not been "big ticket" items, but small, portable items, such as the ivory miniatures belonging to Canadian art collector Ken Thomson stolen from the Art Gallery of Ontario in 2004 (Vignette 1); a pistol from the new Canadian War Museum in 2005, **before** it opened (subsequently returned a day or two later); two First Nations jackets stolen from the Perth Museum in July 2005; antique quilts, medals, and a silver watch stolen from the North Lanark Regional Museum in December 2005, some of which have now been returned; and jewelled slippers and jewellery from the Bata Shoe Museum in Toronto in January 2006. An exception was when two cannons were stolen during the night from Fort Beauséjour, New Brunswick, in June 2005, neither of which was small, or easily portable!

Most of the reported incidents of internal thefts in museums and libraries in recent years have not been in Canadian institutions; however, this does not mean that internal theft is not a problem in Canada. It may be that Canadian cultural institutions do not wish to attract adverse publicity or higher insurance premiums, or that the story is not newsworthy. Staff and researchers have ready and easy access to collections, and while at first these thefts may go unnoticed, be isolated and opportunistic, over time as these losses accumulate and become apparent, a pattern emerges that the threat must have come from within, was systematic and, therefore, premeditated. Many of these items may end up in private collections or put up for sale on the Internet. The theft of 221 religious icons, jewellery, and other precious items from the State Hermitage Museum in St. Petersburg, Russia, in July 2006, involved employees over several years. In 2005, the British Library reported that 8,000 books had gone missing since it moved to its new premises in 1998; however, staff claimed that the books may have been mis-shelved or wrongly catalogued — which emphasizes the need for good cataloguing and auditing of collections. Suffice to say, that for every theft that becomes public knowledge, there are probably many more that are not reported.

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Vandalism

Vandalism is the wilful or premeditated inflicting of damage to an asset, which may include destruction or disfigurement. Very few acts of vandalism turn out to be premeditated; most are opportunistic, again carried out by visitors, by mentally unstable visitors, or by visitors under the influence of drugs or alcohol. In the United States in 1997, about 40% of vandalism arrests were males below the age of 18. The U.S. Federal Bureau of Investigation (FBI) reports that the juvenile arrest rate peaked at age 16. Within the heritage field, historically, there have been cases where paintings or statues have been targeted for deliberate damage to make a political point by activists and protestors, such as the attack with a hatchet by a militant suffragette on Velasquez's painting **The Toilet of Venus**, known as the **Rokeby Venus**, at the National Gallery in London in 1914 to draw attention to women being denied the vote. Others are committed by deranged people, such as when **The Night Watch** by Rembrandt was attacked with a knife in 1975. Large pieces of canvas were lying on the floor after a mentally disturbed patient cut the painting. In 1990, a man with an acid spray attacked the same painting. The acid had only penetrated the varnish layer of the painting. Unfortunately, there is still some visible evidence of the previous damage by the knife used in the 1975 attack. Other examples of vandalism can be found in Vignette 2.

Outside vandalism is also a serious problem. In the Notre-Dame-des-Neiges cemetery in Montreal, the third largest cemetery in North America, hundreds of sculptures were stolen and vandalized in summer 2002 (Gravenor 2002). Some vandalism to places of worship (as well as arson to churches and synagogues) and cemeteries has been the result of "hate crimes" against ethnic or religious communities.

3. **Assess the risks**

   Evaluate the security measures in place for preventing threats from occurring by carrying out a risk assessment.

4. **Recommend security measures**

   Based on the evaluation of the risk assessment, if current measures are found to be inadequate then new or additional measures will need to be implemented to provide effective safeguards.

   High-profile, highly valuable items will require a higher level of protection because of their status, but at greatest risk may be portable items, which may be the subject of an opportunistic, rather than premeditated act.

   When a museum stages an exhibition containing controversial exhibits, or those from certain countries, or hosts a state banquet or other function for visiting dignitaries, or are near other buildings that may be targeted for demonstrations or an attack, the institution will need to apply more stringent measures to enhance its security specifically for those circumstances. Some world cultural and historic icons may also be considered to be targets by terrorists.

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Control strategy: Protect, detect, response, and recover

The primary goal of the control strategy is to deter or block potential thefts or acts of vandalism from occurring. If the building is well secured with good physical and psychological barriers (blocking), has good detection monitors, and a fast response, most of these actions will be deterred. These barriers should also create a means of delaying the thief from escaping with the asset. If **Detect** and **Response** fail, the last goal is to **Recover** the missing objects.

It is important that the overall concept of **Protect**, **Detect**, and **Response** is supported by a security policy.

Protect

Zoning approach

A common integrated approach to minimize the risk of threats in museums and any other cultural institution is to design the site, building, and its compartments as a series of defensible spaces referred as zones. From outside to inside, protection is increased while usually restricting access to visitors and staff. See Figure 1 as an example of zones in a museum. The zones are designed using the strategies of **Protect**, **Detect**, and **Response** according to the function of the zone, the level of security required, and the resources available. Limited access of personnel to some zones will reduce the risk of opportunistic threat from staff. Table 1 shows the five typical zones in museums. Some control measures (**Protect** and **Detect**), will be proposed below for each of those zones. More information on control measures for the different zones can be found in RCMP (2000 and 2007).

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

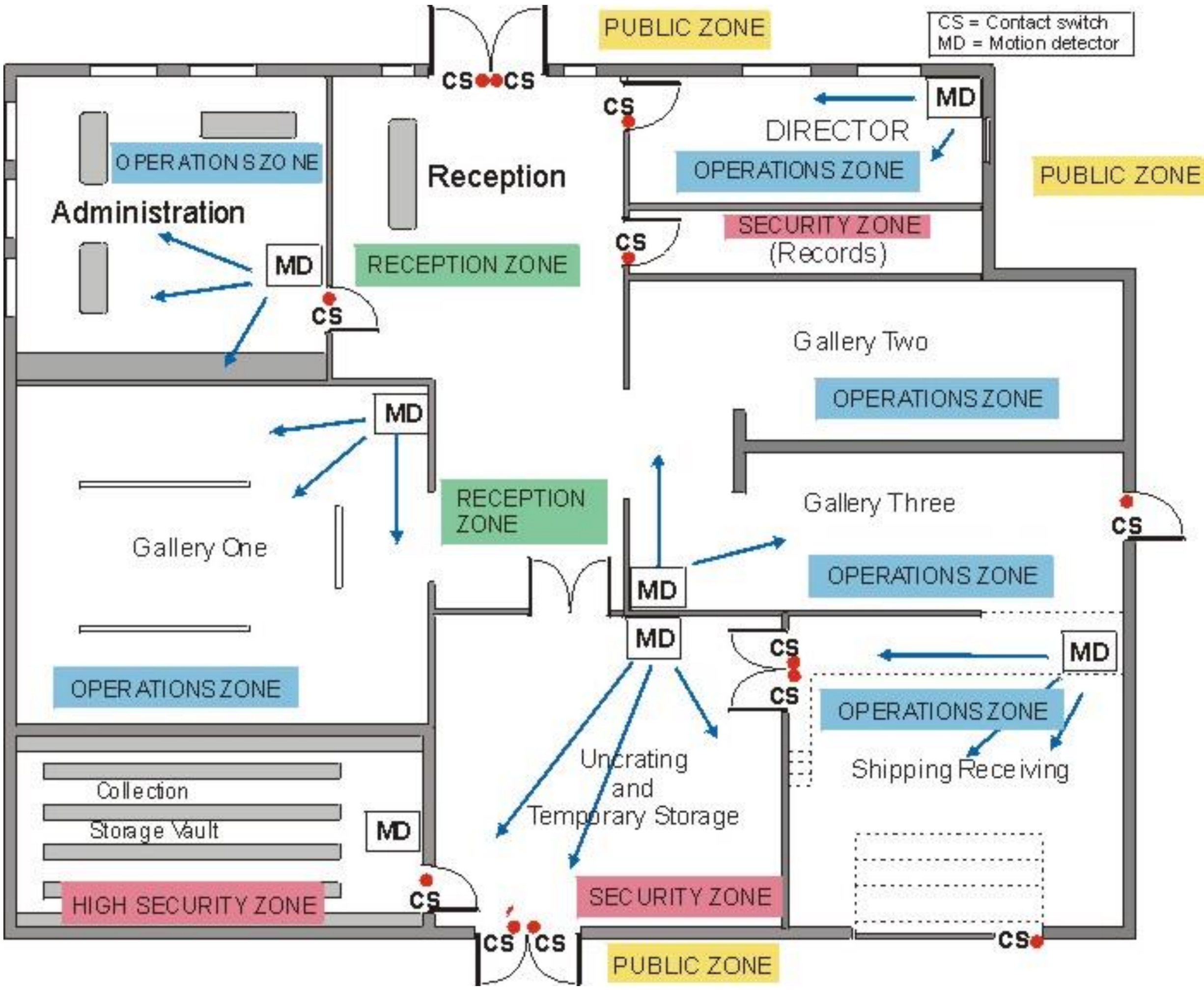

Figure 1. Security zones, CS: contact switches, MD: motion detectors, and 1 – 15: intrusion alarm system inputs. It should be noted that while the RCMP (and this section) follows the Government of Canada Security Policy (GSP) in determining what should be covered under each zone, the arrangements for a museum or art gallery tend to be somewhat different. The exhibit or display space is generally regarded as an operational zone because access to it is controlled.

Security zoning

Public zone

- Exterior concourse
- Public parking
- Foyer, lobby
- Cafeteria
- Shops
- Auditorium/ lecture rooms

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Reception zone

- Visitors, staff, and vehicle entrances

Operations zone

- Exhibition areas, study rooms
- Boardroom, administration, general office areas
- Collection packing and unpacking areas
- Loading bay: shipping and receiving
- Mailrooms
- Workshops, preparation area
- Telephone and hydro room
- Maintenance rooms, furnace/ environmental control room

Security zone

- Conservation laboratories
- Managerial offices that display collection items
- Photographic studio
- Overnight collection storage
- Money, records, or any attractive item storage

High-security zone

- Permanent and temporary storage vault
- Security operations control room
- Server room

Public zone

The Public zones are areas surrounding or forming part of the facility to which the public has access. Cafeteria, shops, and auditorium are usually considered a Public Zone even if visitors must walk through a Reception Zone to enter those locations. In this zone, the safety features related to the building perimeter will be also included.

Exterior

The choice of site for new buildings should be carefully considered. Buildings located in an isolated area or a high crime rate area are likely to be at a higher risk.

Many of the risks to an existing building can be avoided or mitigated, starting with the landscape surrounding it. It should not provide cover for intruders, but provide an unobstructed line of sight of any problem areas (i.e. allowing surveillance by security staff or cameras). Institutional property should be marked with signs, landscaping, or fencing. To ensure a full clear line of sight year-round, tree branches

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

should be trimmed 1.5 meters (m) from the ground, and hedges should be no higher than 0.4 m. Trees should be at least 6 m away from the building, otherwise the roof access should be monitored for intrusion. This also helps prevent rodents and other pests from entering (section on Pests).

Car parks should be well lit. Encourage all staff and visitors to lock their vehicles and secure valuables in the trunk to deter thieves. Thieves may climb on vehicles to access the building; therefore, all vehicles should be parked away from the building. This also can help mitigate the effects of car bombs, and can prevent thieves from concealing themselves. Ensure that no emergency exits are blocked at any time by parked vehicles.

Ideally there should be exterior security lighting above all entrances and exits. This lighting should be protected from vandalism by being enclosed in a vandal-proof casing. The security lighting should also have sufficient light intensity to illuminate the surrounding area and entrances including all emergency exits and loading bays.

Perimeter of building

The perimeter of the building is often the first defensible space for the museum where access is possible only through the Reception Zone. The structure of the building, external doors, windows, and Heating, ventilation, and air-conditioning (HVAC) system ducts must be reinforced, if possible, using heavy-duty commercial hardware and have an adequate detection system. Figure 2 summarizes protection for a small-size museum.

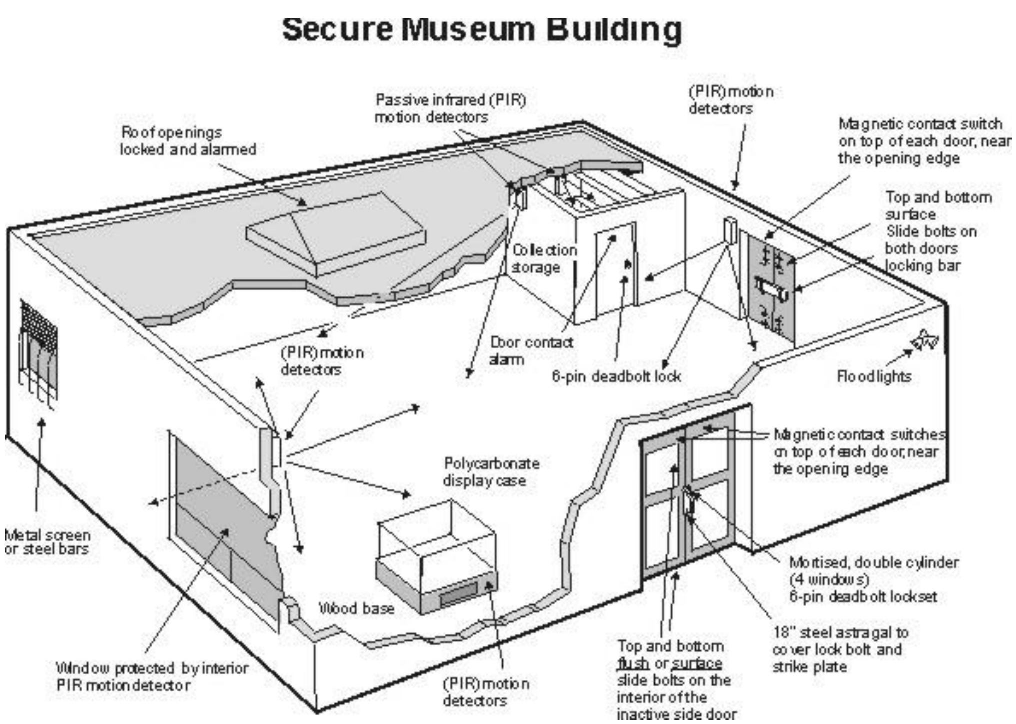

Figure 2. Example of security for a small-size museum.

The materials used in constructing a building will also play a role in how resistant it is to penetration. A solid brick or concrete structure will be more secure than a wooden structure. Ensure that the building is in a good state of repair at all times. Access points such as doors and windows that are in concealed areas, open, or are easily broken or removed, can be attractive to criminals; therefore, ensure that all doors and windows are closed and locked at the end of the day. More details on door hardware can be found in Kelly (1998).

Windows within 3 m from grade require reinforcing with window bars, security glazing, or window film for extra security against penetration. If they can be opened, locks, magnetic contacts, and near-by glass-break detectors should be installed.

The rooftop mechanical room, skylights, and vents should be secured and alarmed against intrusion. Ladders and overhanging branches from adjacent trees, that may assist access, should be removed.

HVAC ducts and vents, which exceed 930 cm^2 in cross-sectional area (unless the smallest dimension is not more than 150 millimeter (mm)), should have security screens, especially if they are located at less than 3 m above the ground or located at the roof.

During construction or renovation, a building is much more vulnerable to penetration. Scaffolding around a building provides an easy point of access for the would-be thief. The museum must provide additional perimeter security (i.e. security guards) and not allow contractors into secure areas unsupervised.

Reception zone

The Reception Zone is an area where information may be provided or obtained and where access by staff, visitors, contractors, etc. into an operational zone or a security zone can be controlled. Access may be limited to specific times of day or for specific reasons. This zone is set up as a base from which secure zones are developed. Staff the control point with personnel who are usually responsible for controlling access to the Operations and other Security zones, by issuing passes and keys, providing general information, responding to telephone requests, monitoring the fire alarm panel, monitoring the closed-circuit television cameras (CCTV) surveillance system, monitoring traffic within the Public Zone, and monitoring the security portable radio network. A panic button hidden behind the counter may also be useful.

Visitor entrance

Minimal: There should be a person assigned to supervise traffic flow (i.e. receptionist, interpretive staff, volunteer, or docent) who is trained to follow established access control procedures (i.e. contact information for emergencies).

Optimal: There should be at least one security guard to carry out the above duties. In addition, this may also require using barriers, turnstiles, or revolving doors to control traffic flow.

More and more in Europe and in the United States, public places such as museums and libraries are using metal detection to screen visitors.

Staff entrance

There should be one person keeping a record of staff access during and after opening hours using a sign-in sheet **or** electronic tracking system for staff access (i.e. card swipe or proximity card). In small museums and historic houses, this may be at the front desk, while in larger, national museums, there is usually a separate staff entrance.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Loading bay

The loading bay is considered to be an Operations Zone due to the activities that must be supervised. The loading bay may have its own reception desk; otherwise, a centralized reception desk can control and monitor the access at distance.

Operations zone

Access to this zone is well controlled either by the Reception Zone or by dedicated measures such as guards, monitors, or key access. Exhibit areas are Operations zones accessible to the public during open hours accompanied by additional security measures, such as more guards on post. In this way, the exhibition areas become temporary, well-protected Public zones. The remainder of the time, they are locked down and all visitors or contractors are escorted. The study room is also an Operations Zone where visitors are closely monitored. The other Operations zones are usually non-public access. Some of those areas may have objects present for short-term purposes, such as a photographic studio, workshop, or preparation and packing areas. Areas such as offices, boardroom, and maintenance rooms are Operations zones and may be accessible to most staff. Contractors and visitors are usually escorted.

Exhibit area(s)

Display areas are particularly vulnerable where no security guard or staff member is present, such as in some smaller community museums; when barriers and surveillance are insufficient or non-existent; or when small and/or unsecured items are displayed near exits or windows.

Open displays where exhibits on free-standing plinths, bookcases (e.g. in an historic house), pictures hanging on walls, or outdoor exhibits (i.e. on a campus or on the grounds of a museum or art gallery) present problems if they are not properly secured, wired to an alarm system, or if barriers or proximity alarms are not installed to prevent visitors from coming too close.

There are a number of ways to protect objects on display. The easiest and cheapest are by using:

Minimal: Stationing guards or volunteers throughout the building, particularly where vulnerable objects are located; installing psychological barriers such as cords, signs, raised platforms, etc. to deter people from coming too close to exhibits.

Optimal: Installing monitored passive infrared motion detectors (PIR), proximity alarms, and other surveillance systems in display areas at night (all of which may be combined with barriers); and firmly attaching security hardware to frames hanging on walls, and to exhibits on plinths or in display cases.

Additional security for loaned exhibits, exhibit items of particular value, or exhibits that are considered controversial should be established. As well, security staff should politely warn visitors not to get too close to exhibits. This will strengthen security even further. When installing a new exhibit, ensure that, if the configuration of temporary partition walls changes with each display, the exhibit space is fully protected by rearranging security devices, such as PIRs or CCTV, so that their field of vision is not obstructed, or "blind spots" are created. This work should only be carried out by a licensed security professional. Arrange displays so that there are no areas where people can conceal themselves.

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Display cases

Display cases are another defensible space level in the Operations Zone. They require protection with security screws, locks, and, in special circumstances, alarms. Display cases, if not properly constructed, or unglazed framed artworks are often the weakest links in the security of a museum or art gallery, given that intrusion alarm devices are turned off during opening hours, and may be the only means of preventing an item from being damaged or stolen.

For display cases, use polycarbonate or acrylic at least 10 mm thick (d in.). If glass must be used, it should be shatterproof. Many products available will withstand high impact from sledgehammers, baseball bats, or even some firearms, depending on the structure of the display case. Protective plastic films, normally used on windows, are now available that are also explosion-proof. To secure display cases, always use:

Minimal:

- Non-removable, tamper-proof security screws, locks, brackets, and hanging devices that can only be loosened or removed by using a customized implement.

Optimal: For those items that require additional protection, use:

- alarmed pressure pads around/in front of cases, or on pedestals displaying valuable objects; and/or
- glass-break sensors in display cases housing valuable items;
- proximity alarms referred to as EMC units (electromagnetic capacitance) consisting of plates built into the walls (of display rooms), or attached to objects. When someone comes too close or tries to remove a painting, an alarm (which can be silent) goes off. The alarm can also be linked into CCTV systems. These alarms, working off a radio frequency of 25 Khz, can be strips on windows, on plinths for sculptures, or floor electrodes. They can also be triggered by rapid changes in relative humidity. Because of the force field created, they are not recommended for pastels and other friable media; and
- radio frequency identification devices (RFIDs). The RFID tag can be attached to or implanted in the item and tracked using a radio frequency. There is no data currently available regarding their practicality on museum artifacts because few institutions in North America have installed them; although, they are gaining prominence in Europe.

Check display cases at the end of the day to ensure they have not been tampered with. Keep cabinets or cupboards in historic houses locked at all times.

Study rooms

Researchers and members of the public should never be left alone or allowed to roam unescorted. Ensure that doors to these areas are kept locked at all times when not in use. Any entry into a restricted area, whether by an authorized member of staff or other persons should be carefully controlled and accurate records kept both on-and off-site either using a sign-in sheet, key control, or card access system.

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General office areas

Doors should be lockable using security lock hardware. If there are windows at ground level, install either motion sensors (PIRs) and/or glass-break detectors, or apply security window film. Safes or cabinets housing money or confidential files within these offices should be kept locked when the occupant leaves the room.

Loading bay (shipping/receiving)

Minimal: A dedicated person should control the door during opening hours, with no one allowed access after open hours. All deliveries should be received in this area. Access to these areas should be registered; exposed hinges of the doors must have non-removable pins or be modified to prevent hinge pin removal; area should be supervised by one person; area should have metal doors and deadbolt lock.

Optimal: As above, but with monitoring 24–7. There should also be a CCTV camera trained on the door and an intercom system.

Maintenance rooms, janitorial supplies

Doors should be lockable using security lock hardware.

Telephone rooms, hydro room, furnace/environmental control room

Doors should be lockable using security lock hardware. Access by authorized persons to these areas should be registered; exposed hinges of the doors must have non-removable pins or be modified to prevent hinge pin removal; area should be supervised by one person; area should have metal doors and deadbolt lock. There should also be a partial key control (not audited).

Security zones

Security Zones are areas accessible only to authorized personnel; visitors and contractors must be escorted. The zones are accessible through the Operations Zone or sometimes directly through the Reception Zone. Security zones include areas where collections are stored temporarily or permanently or where any high-value assets are present. Some institutions may have a superior level of security referred as a High Security Zone. A High Security Zone is one that requires stricter access control than regular Security zones. The overall integrity of the museum's security would be at risk if one of these zones were infiltrated by non-authorized or non-escorted persons.

Permanent storage vault, temporary storage vault, overnight collection storage

Minimal: Doors should be lockable using security lock hardware. Locks should be keyed separately. The doors should be metal; internal walls should be reinforced (slab-to-slab construction). Access to these areas should be registered and restricted only to those who require access in order to do their work; exposed door hinges must have non-removable pins or be modified to prevent hinge pin removal.

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Optimal: Install a PIR and a CCTV camera trained on the door.

Conservation laboratory, offices with objects, and photographic studio

Valuable items are not generally stored in this area permanently, but they may need to remain overnight or for several days or even several months. Access should be restricted to authorized persons only. Doors should be lockable using security lock hardware. Depending on where the room is located within the building, it may require a motion sensor.

Server room

Due to highly valuable data and the dependency of institutions and staff on computer technology, the server room is sometimes classified as a High Security Zone. Personal computers and servers may contain very important data related to the collection, such as provenance information or value, the loss of which may have major consequences for the significance of some objects. Access to the server room is typically limited to Information Technology staff. More information on safeguards for server rooms can be found at RCMP (1997).

Money and records storage

Doors should be lockable using security lock hardware. Safes or cabinets housing money or confidential files in this area should be kept locked when the occupant leaves the room. Files should be stored according to their security classification. Depending on where the room is located in the building, a motion sensor may be required. Ideally, rooms housing classified files should be internal, with no external walls or windows. The door should be metal; internal walls should be reinforced (slab-to-slab construction). Access should be restricted to authorized persons only.

Security control room

Security control rooms in medium- to large-size museums and galleries are frequently located away from public areas and require a card access or a keypad to access them. They should be kept locked at all times. These rooms should house a locked key press for storing and issuing all keys and passes. Doors should be lockable using security lock hardware. Locks should be keyed separately. As money and records storage doors should be, the doors should be metal and internal walls should be reinforced (slab-to-slab construction). Access to these areas should be registered. Exposed door hinges must have non-removable pins or be modified to prevent hinge pin removal. When the security desk is at reception, it may not be regarded as being entirely within a Security Zone.

Building access control

Allowing access to a given area will depend on the on the type of Security Zone. Access control ensures that visitors and staff are able to enter and leave the building or site in a controlled way; provides a safe environment; and provides levels of access to collections and facilities to staff and the public. Allowing access also means controlling keys and identity cards. Un-logged key distribution or a lack of ID cards or passes make unauthorized entry easy.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Detect

Early detection should be a major consideration. It enables responders (police, security, staff) to mitigate the effects of an incident. Presence of detection measures and their activation can deter adverse actions. There are four distinct steps to detection:

- Notice the event.
- Convey information regarding the event to an analysis centre (i.e. security control room, monitoring centre).
- Analyze the information received.
- Evaluate if the event is unauthorized, then initiate intervention.

Each security system should be designed to have built-in redundancy so that should one type of device fail, the other devices will automatically take over. Installation, maintenance, and monitoring of the system should be carried out by a reputable, certified security company (i.e. a member of the Canadian Security Association (CANASA), who can also advise on the best locations for individual devices to be installed). These systems should be Canadian Standards Association (CSA) or Underwriters' Laboratory of Canada (ULC 2003) or Underwriters' Laboratory (UL) (USA) approved, or other equivalents. As well, the system should be hard-wired into a 24-hour monitoring service, be it police, fire department, emergency dispatch service, or commercial security company. For any security system to function under emergency conditions, there must be an alternative source of power (emergency generators) or an uninterrupted power supply (UPS). In the event of a major power failure, most security systems have only enough battery power to support them for 6 to 8 hours.

Detectors

Most security systems will incorporate magnetic contact switches on doors and windows, glass- break sensors, and various types of verified, PIRs. These motion detectors can function differently for walls (curtain type), as well as have wide-angle and long-range capabilities. Other types frequently used are active infrared detectors (sometimes referred to as photoelectric beams) consisting of separate transmitters and receivers; adaptive radar; ultrasonic; and dual technology detectors employing both passive infrared and microwaves. It is generally recommended that all motion sensors be verified at least twice a year by conducting a "walkabout" in the area where they are installed to ensure they are all working. Some security companies recommend once a month, while some museums claim to do this every night, and some systems will verify on a continuous basis.

Closed-circuit television cameras (CCTV)

There is sometimes a tendency to over rely on CCTV as a substitute for security staff within an institution. If CCTV cameras are to be installed throughout a museum or gallery, or in high-risk areas, such as loading bays, vaults, museum shops, or site perimeter, they must be monitored in real time by a receptionist or guard who can react to an incident; otherwise, CCTV will only provide a record of the incident — which may be useful in an investigation, but will not necessarily prevent the incident from occurring. In reality, monitoring does not always occur in real time — cameras may or may not be recording, and security guards will not be viewing their monitors on an on-going basis. CCTV cameras are capable of monitoring in black-and-white or colour; and in infrared for night viewing capability (especially outside) using wide-angle or standard lenses. They can also have a motion analysis capability, real time or time delay, or remote monitoring capability linked to a personal computer.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Two examples of robbery in museums having CCTV in place can be found in Vignette 1.

On-site security staff

The installation of security equipment and devices can lead to a false sense of security, and are no substitute for trained security staff present in the public areas. Having an on-site security presence can deter the would-be thief or vandal. However, in smaller institutions and those with limited budgets, it may be unrealistic to provide security guards on a 24–7 basis. Staff, volunteers, or docents can provide "passive security" during opening hours, either at reception or periodically patrolling the building(s), and calling the police to deal with any problems that may arise. However, training in security should be provided to any member of staff having to fulfill that role.

Response

While much effort may be required to prevent a criminal act by using means to **Avoid** or **Block** it, the incident may still be prevented if there is a quick response once the alarm system has been activated. However, it is not expected that a small- or medium-size museum will have the qualified staff to arrest a thief or vandal in the act of committing a crime. The safety and security of the staff is the main priority. In larger museums, security guards must have received instructions as part of their ongoing training regarding what they can and cannot do legally in terms of apprehending a thief or vandal, or someone simply being a nuisance (e.g. making a citizen's arrest, physical contact, restraint, dealing with difficult people, etc.).

When an alarm sounds, security staff will be directed to the area where the incident has occurred and, if necessary, summon the police. They should first secure the area and restrict access to only those needing to be there. If an incident is in progress, security staff should not attempt to restrain a thief if the person is violent or armed. At all times, everyone should try to remain calm and co-operate with whatever the thief demands. Anyone witnessing the incident should try to memorize as much about the perpetrator as possible, such as:

- height and build
- colour of hair and eyes
- facial features
- clothing – what was he wearing?
- how he spoke/what he said – did he have an accent?
- whether he was armed or whether there were any accomplices

This information will be useful to the police and support visual evidence from CCTV cameras.

Immediately after the incident, a full review of the institution's security (to include policies, practices, procedures, and equipment) will be required. This may include recommending that upgrading security devices and enhancing security procedures be implemented.

If an item has been damaged, or a painting cut from a frame, nothing should be touched until the police and conservators (if in place) have been able to collect physical evidence, fragments, etc. Nor should anything be touched if a break-in has been discovered after-hours (such as locks being forced, windows broken, etc.).

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Recover

Stolen objects must be reported to the police immediately. Documentation is very important. A full description of the objects, accompanied by photographs and a condition report, if available, should be provided to the police. ICOM's CIDOC group (International Committee for Documentation) has developed guidelines for this. Unfortunately, the rate of recovery is generally low (less than 10 –15%) after about the first two to three weeks, and may involve protracted police investigations and legal procedures, maybe even repatriation. Paintings stolen from the Isabella Stewart Gardner Museum in Boston in 1990 have not been recovered, but on the positive side, the Goya painting **Children with a Cart** stolen while in transit between the Toledo Museum in Ohio and the Guggenheim in New York City in November 2006 was recovered by the FBI after only a couple of weeks.

Recovery will also require that a full review of the institution's security (to include policies, practices, procedures, and equipment) take place immediately after the incident, with recommendations to possibly upgrade security devices and enhance security procedures. It may be that the alleged missing item has actually been "displaced" not stolen, owing to poor record-keeping or storage practices.

Security policy

In addition to physical hardware and systems, all institutions should have a security policy covering all aspects of security. It should not simply be a series of "post orders" for security guards. These should include:

1. **Access control/Key control:**Implement a key control policy, and enforce it. Ensure that:
    - only those persons requiring keys are issued with them;
    - keys are a type that cannot be duplicated without permission; and
    - all keys are returned at the end of a person's employment.
2. **Building security:** Other issues relating to building security, such as bag policy – whether bags are allowed into exhibit spaces, size, type, umbrellas, etc.
3. **Duties of security guards:** Often referred to as "post orders." These should outline who is assigned to where, how often patrols should be carried out, what to do in specific situations, etc.
4. **Security screening:** Employers normally require that all employees (full-time, part-time, and volunteers) undergo a mandatory background check as a prerequisite of the job, which will include a credit check and criminal background check.
5. **Emergency preparedness and response:** Some procedures may already be included in security guards' post orders, while reference should be made to an emergency response plan and/or business continuity plan.
6. **Camera policy:** Whether cameras or other photographic equipment should be allowed into the exhibit space and restrictions on what can/cannot be photographed, use of flash, etc. This policy should also address lighting equipment used by contract photographers as well as film and TV crews.
7. **Procedures for dealing with film/TV crews:**Many institutions are now being used as sets for TV shows, films, and commercials. Guidelines should be prepared to cover which areas are off limits, what can be handled or used, how a track for camera dollies should be laid and where, the use of additional lighting, garbage disposal, etc.
8. **Extra-curricular activities:** Use of premises after-hours by other organizations (i.e. evening classes, wedding receptions, etc.).

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

9. **Construction:** Including renovation and maintenance, to include contractors' access to restricted areas, supervision of contractors, use of welding equipment, whether contractors need to be security screened, temporary disabling of alarm systems (security, fire).
10. **Audit curator collection:** To discourage internal theft and to assess which objects might be missing, it is recommended that a collection audit (such as 1% of the collection) be carried out every 5 years, or collection from a site, building, or part of the collection be audited every 10 years.

More information on security policies and guidelines can be found in the American Library Association (2001) and ASIS (2002) references.

Key control

As part of a building access control system, it is important to enforce a documented key control policy that determines:

- who has access to which keys and when (a need to access as part of a person's function and not because of an individual's title);
- how often keys and lock tumblers should be changed;
- secure storage of keys;
- return of keys when staff resign/retire; and
- a key audit program.

Keep a key log and store extra keys in a secure location (i.e. steel key press). Access to and throughout a building can be controlled using a master key system that will vary according to the size of the building. In a small museum or historic house, a one-level master keying system can be used. In a typical set up, the front entrance door and rear entrance door would be keyed to change key A, but are not on the master key. The vault or storage area is also a registered keyway, but not keyed to the master key. Each office or room would be keyed to a change key (A, A, A, etc.) and to the master key. Offices or rooms can be keyed alike, or keyed differently. The master key should be kept in the office in a secured container such as a key press. More detailed information on a key control system can be found in Kelly (1998).

All locks and tumblers on exterior doors and collections storage areas should be reset and new keys issued on a regular basis. The normal time period recommended by security experts for resetting locks and tumblers and reissuing keys is once every two to three years. This is particularly important if keys are lost or if employees who have left have not returned their keys. These locks should be dead bolts, with 6-pin tumblers.

If a card access system is used, cards can be programmed to allow restricted or unlimited access to specific staff members to various parts of the building. This should also form part of the museum's overall security policy.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Vignettes

Vignette 1. Thefts from a display case

A collection of ivory miniatures, recovered as a result of CCTV video surveillance tapes (a typical CCTV surveillance station is shown in Figure 3), was stolen from a locked display case at the Art Gallery of Ontario in 2005. The five miniatures, valued at $1,500,000, were stolen when the display case was prised open. In another incident, miniatures worth about $230,000 were stolen from Hever Castle in England, when thieves, working as a team, were able to distract the guide who was responsible for covering several rooms and prise open a padlocked case. In the second incident, while the thief has been convicted, the miniatures have not been recovered.

In both incidents, the display case was locked, but was prised open. Neither case was alarmed. In the first incident, CCTV surveillance was able to record the incident. The tape was used in recovering the items. This was not the case in the second incident. In both incidents, the items stolen were small and portable. The first incidence appears to have been a "target of opportunity," but in the second, there are indications from the subsequent trial that this may have been a commissioned theft and that the premises had been previously "cased" by the criminals involved. Both incidents illustrate:

- that it is imperative that anything small and valuable be properly protected by sturdy, thief-resistant display cases, which are both locked securely and, if necessary, alarmed;
- the need for adequate security personnel in the display areas who are able to act quickly to apprehend the thieves; and
- that CCTV may act as a deterrent in some cases, but usually only provides proof of an incident that has occurred; it does not always **prevent** an incident.

Vignette 2. Vandalism of artworks

In January 2005, two oil paintings, **Woman with a Revolver** and **Surveyor** by Canadian artist Alex Colville were damaged with a small sharp object at the Mendel Art Gallery in Saskatoon, Saskatchewan. Another incident involved a large Leonardo da Vinci cartoon **Madonna and Child with Saint Anne and the Young Saint John** being blasted with a shotgun at the National Gallery in London in 1987. In a third incident, acid was thrown onto Rembrandt's **Danae** painting at the State Hermitage Museum in St. Petersburg, Russia, in 1985. None of the artworks had been glazed with impact-resistant glass or Plexiglas, although the Leonardo had been glazed with laminated glass.

These incidents illustrate:

- the need for artworks to be glazed to protect them from vandalism. In each case, damage would have been eliminated or reduced;
- the use of proximity alarms to prevent visitors getting too close;
- the need for close observation by guards of visitors' body language; and
- the installation of metal detectors at entrances to the museum or exhibit area(s) to prevent incidents if the item is of high value or controversial.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

References (key readings)

1. Kelly, W. **Security Hardware and Security System Planning for Museums.** CCI Technical Bulletin Nº 19. Ottawa: Minister of Public Works & Government Services, 1998.
2. Liston, David, ed. **Museum Security and Protection**. London; New York: Routledge, 1993.
3. Shuman, Bruce A. **Library Security and Safety Handbook. Prevention, Policies and Procedures.** (Chicago; London: American Library Association, 1999.

Websites

1. American Library Association Map Collection Security Guidelines, June 2010. (PDF Version, 123 KB) on December 03, 2010.
2. American Library Association Guidelines Regarding Thefts in Libraries on August 13, 2008 (Chicago: American Library Association), January 2003.
3. Architects Security Group Inc. Welcome. on December 03, 2010.
4. Gravenor, Kristian. "Graverobbers" delight: Hand wringing abounds as cemetery creeps steal bronze sculptures, on March 26, 2007. Montreal Mirror 2002.
5. ICOM-CIDOC, on December 03, 2010.
6. Royal Canadian Mounted Police (RCMP). Physical Security Guides and Reports on December 03, 2010.

Websites (key readings)

1. American Library Association/Association of College & Research Libraries Guidelines for the Security of Rare Books, Manuscripts, and Other Special Collections on December 03, 2010 (Chicago: American Library Association), January 2006.
2. The American Society for Industrial Security. Suggested Guidelines in Museum Security (c. 1997), revised November 2002 (PDF Version, 111 KB) on December 03, 2010.

Thanks to the Centro Nacional de Conservación y Restauración in Chile, the Canadian Conservation Institute's web resource Agents of deterioration, translated into Spanish by ICCROM, is now available free of charge. Intended for curators and conservators, the resource identifies 10 primary threats specific to heritage environments.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Fire

Deborah Stewart

Introduction

No institution is immune from the risk of fire. Unlike other agents of deterioration covered in this resource, serious damage or total loss of the building, collections, operations, and services can occur. Personal injury — or even death — may also occur. As a result, it is important that fire prevention and fire control be given the highest priority possible. As well, every effort should be made to reduce the risk of a fire from occurring and to minimize its effects. While the cost of doing so may seem prohibitive, the cost of doing nothing may be even greater.

Because life safety issues are under the jurisdiction of government authorities, they will not be covered in this section. Instead, it will look at fire safety and protection from the perspective of preserving and protecting cultural property, and collections in particular. While many museums may meet basic requirements for life safety, too often these requirements are inadequate to protect cultural property.

Brief fire theory: Principles of combustion

Fire is the state of combustion resulting from a chemical reaction that requires the presence of three elements in proper combination — a fuel source (anything that burns), oxygen (a component of air), and an ignition source such as heat or a spark — in order to begin and develop. This is often referred to as a "Fire Triangle," as shown in Figure 1.

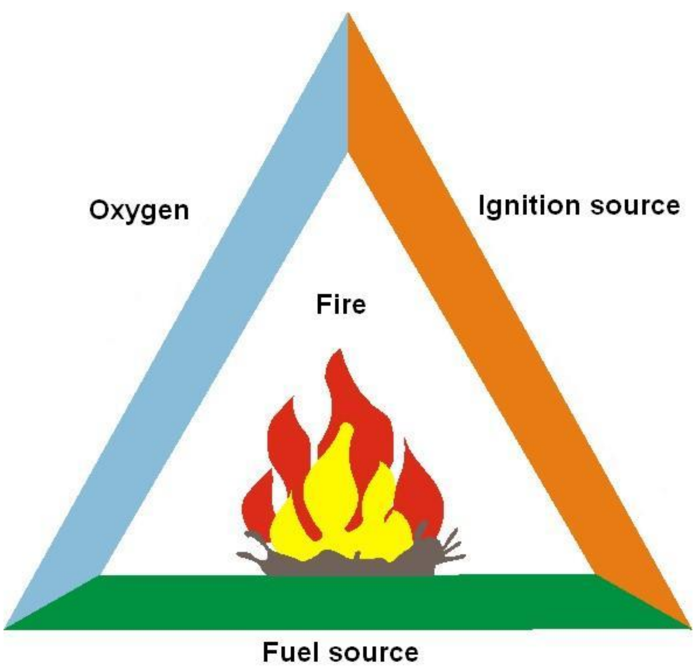

Figure 1. Fire Triangle

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Extinguishing a fire usually involves removing at least one of these elements.

The following briefly describes the various stages of fire.

Main stages of fire development

Pre-flashover stage

Fire remains limited in size initially, and can be easily extinguished using a portable fire extinguisher at first. Detection may not occur until flames become visible or when heat is produced. Sprinklers will activate when sufficient heat is produced at the ceiling. Sprinklers will control and possibly extinguish the fire. Fire will become uncontrolled if an automatic suppression system is not provided. This may lead to the next stage.

Flashover stage

Heat becomes intense and high enough to ignite common combustible materials within the room, leading to a fully developed fire. This can happen within minutes of the pre-flashover stage when the proper conditions are in place.

Post-flashover stage

Fully developed phase of a fire, whereby all exposed combustibles in the room are involved. This may result in total loss of collections within the room; the entire building is threatened. Flames may spread to other rooms through hallways and ceiling voids. Fire will eventually burn out when all combustibles are consumed.

Because fire can grow and spread rapidly, it is important to detect and extinguish it at the earliest stage possible in order to reduce the risk of serious damage, injury or loss.

Sources of fire ignition

While museums and related institutions are vulnerable to fire from a number of different sources both inside and outside the building, most museum fires begin as a result of human neglect and carelessness, or are intentionally set.

Some typical sources of ignition include:

- exterior and natural sources such as lightning, proximity to forest, bush or grass fires, exposure to adjacent burning buildings or exterior trash containers, etc.;
- electrical sources such as faulty or overloaded wiring, electrical panels, electrical equipment and appliances, and HVAC system (heating/ventilation/air conditioning) systems;
- proximity of combustible materials to a heat source such as portable heaters;

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

- open flames such as candles and food warmers used during catered events;
- "interpretive fires" such as fireplaces, cook stoves, candles, blacksmith shops, etc.;
- construction and renovation activities such as hot work (i.e. welding, paint removal, cutting, etc.), the use of casting materials that produce heat, etc.;
- improper use, storage, and/or disposal of flammable liquids such as paint thinners;
- smoking materials;
- gas leaks (Figure 2); and
- arson.

Figure 2. The fire in this museum was caused by a gas leak. Of these sources, the risk of fire from electrical, arson, and construction or renovation sources tend to be the most common in cultural institutions.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

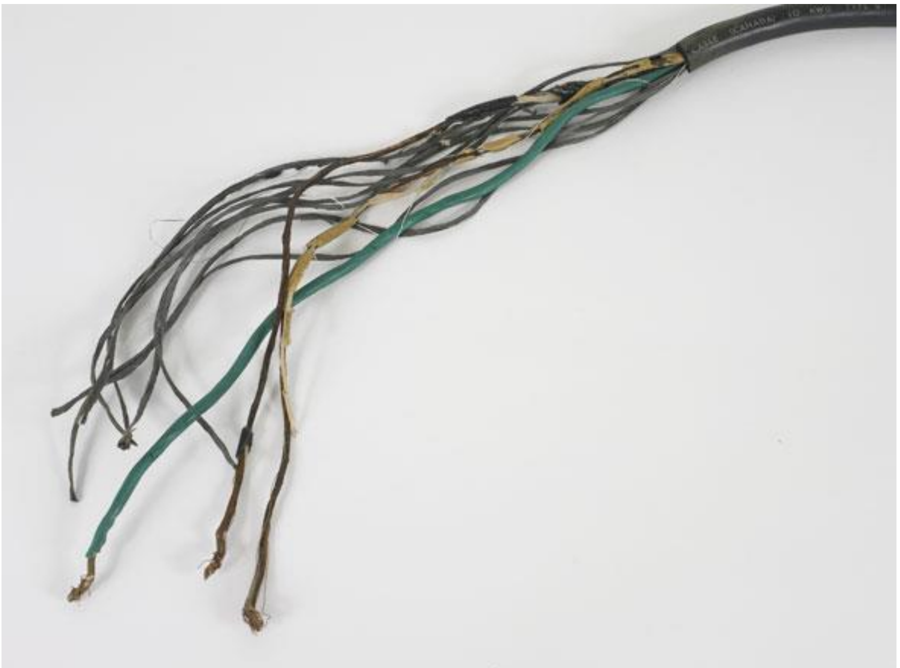


Figure 3. The defective wiring shown here was part of a power supply cord from a laboratory oven. Have the building's electrical system inspected by an electrician at least every 10 years, maintain heating systems annually, and inspect tools, equipment, and appliances — large and small — regularly to reduce the risk of fire from electrical sources.

While collections such as cellulose nitrate film, ammunition, munitions, blasting equipment, flammable liquid ("wet" collections), etc. are usually not the cause of fire, they contribute to the building's fire load, and greatly increase the threat to fire fighters.

Places of worship are particularly vulnerable to arson because they tend to be relatively isolated, kept unlocked for the public's use, and consist of large open spaces and hidden voids that allow fire to spread rapidly. Historic structures sitting vacant or unattended are also highly vulnerable.

Seasonal museums can also be at risk. Because many of these small community museums do not have HVAC system systems, space heaters, portable heaters, and even wood-burning stoves are sometimes used during the spring and fall to help control dampness and to provide heat for staff who may be working in the building. In addition, many small community museums are located in remote locations where acts of vandalism and arson may go undetected for some time, particularly during the "off" season. These museums are often constructed of highly combustible materials, lack monitored fire detection and automatic fire suppression systems, and may not have a reliable water source at hand. Some museums rely on battery-operated smoke alarms; however, it is important that these devices are regularly tested, cleaned, and the batteries changed. While these alarms may suffice in terms of life safety when the building is occupied, during non-working hours, response by the local fire service could be substantially delayed.

Historic house museums are particularly vulnerable to rapid fire growth and can be more problematic to retrofit. Their vulnerability may be due to a number of causes:

- They may be constructed of highly combustible and non-fire resistive materials, which have dried out over time.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

- They may still have older heating systems and electrical wiring that is both hazardous and inadequate.
- Many are designed with large open staircases that allow fire and smoke to rapidly spread between floors.
- There may be concealed voids above ceilings, below floors, and behind walls.
- Many have basements and attics that are not compartmentalized.
- Openings around installed or removed ductwork, electrical conduits, plumbing pipes, etc. may not have been stopped with fire-resistive materials where the penetrations pass through floors, ceilings, and walls.
- Cleaning supplies, solvents, paints, waxes, etc. are often inappropriately stored in the basement or in a non-fire-rated closet.

Fire loading from house contents and finishes may be high; and the facility may be used in ways that present additional fire hazards; for example, using fireplaces or wood-burning stoves to heat the museum or for interpretive purposes such as cooking and baking. In addition, the museum may be rented out for film projects or used for special dinners and meetings where open flames such as candles are permitted. In spite of these hazards, many museums do not have a monitored fire detection system or automatic fire suppression system. However, before making changes to the structure to make it safer, or installing or upgrading fire protection systems, it may be necessary to consult a preservation architect who is experienced in undertaking these kinds of projects while respecting and honouring the historical fabric and design of the structure.

Regardless of whether a museum facility is historic, or modern and purpose-built, it is important to know the building and its systems thoroughly and to keep them well maintained. Unfortunately, all too often fire prevention and protection and building maintenance are put aside, as money and staff time are diverted towards other programs and activities. However, by making fire safety a priority, measures can be taken to protect staff, visitors, collections, building(s), and services from loss and harm. Depending on the extent of damage, recovery and re-opening after a fire may take many years, or may even require erecting a new building. Some museums never recover.

Impact of fire on collections

Depending upon the type, extent, and severity of a fire, and the vulnerability of items to heat and smoke, damage to collections can range from minor discolouration to total loss. Items located in the seat of a hot flaming fire may ignite and burn completely or partially. Even items located elsewhere, for example in another room, may become distorted, discolored or brittle, or covered with a layer of powdery soot as in Figure 4.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

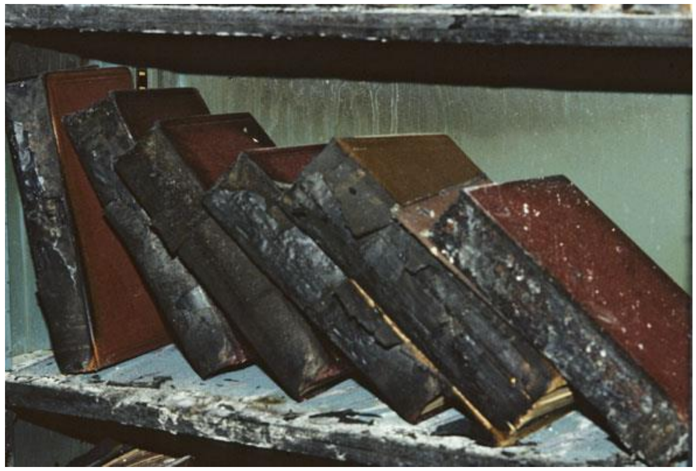
Figure 4. Items inside this display case were largely protected from soot damage.

While damage from heated gases and soot may not result in complete loss, extensive and irreversible damage can still occur (Figure 5).

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Figure 5. Although the top pages were damaged, the rest of this open book remained relatively untouched.

Organic materials from plant and animal products such as paper, textiles, and wood are highly susceptible to combustion, particularly if very dry. In general, the thinner the item, the more likely and quickly it will ignite and burn completely. For example, a single sheet of paper will ignite and burn rapidly, while books packed tightly together on a shelf may remain relatively undamaged except for damage to their spines (Figures 6 and 7), and perhaps soot deposits or discolouration on the head of the books.



Figures 6 and 7. The text blocks of these books remained intact; however, the covers were badly damaged and will need to be replaced.

While items made from inorganic materials such as stone, glass, metal, and ceramic are not likely to ignite, they can still suffer extensive damage such as melting, warping, discolouration, embrittlement, cracking, and even shattering.

In addition to damage from heat, objects can also be seriously damaged by smoke and soot. Smoke is the product of combustion, and generally consists of fine particulates and hot gases, while soot refers to the finely divided carbon deposited by flames during the incomplete combustion of organic substances. Both are damaging to cultural property.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Figure 8. The top surface of this cabinet is covered with a heavy deposit of soot.

Soot deposits, such as on the cabinet in Figure 8, typically result in a powdery, ash-like deposit that can dull, or even obliterate, surface images and details. When soot-covered materials are handled, the soot may be further pressed into the surface. Organic materials with porous or highly textured surfaces are especially vulnerable and may be extremely difficult to clean. As a result, soot-damaged items should be handled as little as possible.

Based on the observations of conservators experienced in salvaging and cleaning soot-damaged objects, soot tends to become more difficult to remove with the passage of time. It should be removed as soon as possible following the directions of an experienced conservator. Soot resulting from a fire involving synthetic materials tends to be oilier and more difficult to remove than powdery soot.

Controlling fire risk

Most museums provide an abundance of fuel to feed a fire. This is particularly true of many historic house museums of wood frame construction, with period rooms full of combustible objects and interior finishes. Archival storage vaults and facilities equipped with movable (compact) storage systems also typically contain high fuel loads.

Some collections may themselves pose a further risk. In the event of a fire, cellulose nitrate film, natural history collections stored in alcohol, and explosives such as munitions and some mining equipment can be particularly dangerous for fire fighters. Where possible, these objects should be rendered safe, modifications to them documented, and practices established and implemented for their safe handling, storage, and display. For hazardous areas such as chemical supply rooms or areas containing hazardous collections, mount warning signs to alert staff - and the fire service – of any dangers.

Some situations that potentially increase a museum's risk of serious damage cannot be avoided; for example, the combustible construction of a wood-frame historic house museum, or the location of a museum in a remote area where the water supply may not be dependable or where the response time of the local fire service may be much longer than in a larger centre. However, measures can still be taken to reduce the risk and severity of fire by developing and implementing fire prevention and response policies, plans and procedures, by enforcing fire safe practices, and by upgrading the facility.

Table 1 identifies some ways to reduce the risk of fire, or to minimize its impact. Measures will vary from one institution to another due to differing needs, resources, and expertise available. Not all measures may apply to your situation, nor is this list exhaustive.

Some strategies for reducing fire risk and damage.

General (all hazards)

- Develop and implement a fire protection program that addresses fire prevention, building upgrades, fire response procedures, fire protection systems and devices, and staff training.
- Establish a fire prevention committee consisting of both management and staff. Meet regularly to discuss fire safety issues.
- Develop and implement fire safety policies, practices, and procedures to create a safe environment for both people and objects. For example: implement a "no smoking" policy; remove clutter and rubbish; prohibit the use of open flames and temporary wiring; prohibit using heat-generating equipment near combustible material; etc.
- Train staff in fire prevention, fire evacuation procedures, and the use of portable fire extinguishers.
- Undertake a risk assessment to identify and prioritize fire threats, plus measures to reduce them.
- Undertake regular inspections and eliminate any hazards found. Use an inspection checklist to make sure that nothing is overlooked.
- Develop a good rapport with your local fire service. Invite all shifts to the museum to familiarize them with its construction, layout, contents, and any hazardous areas such as chemical storage areas, spray paint booths, or areas containing hazardous collections.
- Discuss your concerns about water damage and let the fire service know which is more important — the building or its contents. Ask for ways to make your museum safer, and for information on fire prevention. Hold annual fire evacuation drills.
- Invite a Crime Prevention Officer — or other law enforcement representative — to visit your museum to advise on ways of making it more secure.
- If planning a new facility or renovating an existing one, use non-combustible and fire-resistive materials, divide the building into fire-rated compartments, and install fire protection systems to detect and control fire and smoke. Install or improve fire and smoke barriers where necessary, as well as fire blocks in concealed spaces and vertical and/or horizontal voids to limit the spread of smoke and fire; ensure that any ceiling, wall, and floor penetration are properly stopped; install approved door-holding devices on fire doors normally kept open; and install the automatic shut-down of the ventilation system in the event of a fire. Have the building's electrical service inspected by an electrician every 10 years or after any changes to ensure that it is safe.
- Inspect and maintain all heating and protection systems to keep them in good working order.
- Install the most effective and suitable fire protection equipment and systems possible based on your needs and budget, and maintain them in good working order.
- Undertake measures to protect collections in storage and on display from fire and water damage.
- Develop procedures and plans for dealing with emergency events, handling and salvaging damaged collections, and for protecting over-sized or at-risk items in situ.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Table 1. Some strategies for reducing fire risk and damage.

Lightning	**Install and maintain lightning protection**
Proximity to exposure fires, i.e. • forest, brush, or grass fires • burning buildings	Listen to the news. Keep trees, long grass, and brush cleared back if in a high-risk area. Cover collections to protect them from smoke. Shut down ventilation system. Seal around openings. Wet down site and building(s).
Electrical sources: • faulty or overloaded wiring and electrical panels • faulty electrical equipment or appliances	Have electrical system and work inspected by an electrician. Ensure all equipment and appliances are listed or approved, in good working order, and are turned off and unplugged when not in use. Dispose of items with frayed cords, or where their safe use is suspect. Do not overload circuits. Ensure that fuses and circuit breakers are used appropriately. Avoid using extension cords and multiple plug adaptors. Add more outlets if necessary. Use only CSA (Canadian Standards Association) or ULC (Underwriters' Laboratories of Canada) rated electrical equipment.
Use of open flames and heat sources (i.e. interpretive fires, portable heaters, etc.) Hot work (i.e. welding, cutting, burning)	Keep heat and flames away from combustible materials. Use a fire screen on fireplaces. Keep a fire extinguisher at hand. Maintain a "fire watch" with people who are trained to use extinguishers. Establish a hot work permit system where relevant. Supervise work and maintain a fire watch during work (and for at least one hour afterwards). Remove combustible material from hot work area. Keep an appropriate portable extinguisher at hand and ensure fire protection systems are operational at the end of the day.
Flammable liquids in the building	Keep only small quantities inside the building. Implement correct handling, storage, and disposal procedures. Maintain up-to-date Material Safety Data Sheets (MSDSs) and label containers appropriately. Prohibit the storage of these liquids in mechanical or electrical rooms or near electrical boxes.
Hazardous collections such as cellulose nitrate film, ammunition, explosives, flammable liquid collections, etc.	Examine collections to identify hazardous items. Deactivate items where possible to make them safe to handle and store or exhibit,; label items accordingly, and keep a record of what was done. Store nitrate film using cold storage, or have it copied by an experienced firm and dispose of originals (i.e. consult the fire department regarding safe disposal), or give originals to an archive experienced in storing them safely.
Arson (sometimes used to direct attention away from another crime such as a theft)	Ask a Crime Prevention Officer for advice on ways to make your institution more secure. Keep the building exterior well lit at night; remove any unnecessary materials/items near the building that could be used to fuel a fire; cut back shrubs that could conceal an intruder or arsonist, especially around doors and windows. Ask police to patrol at night. Do security checks on all prospective employees. Hire extra security during controversial exhibits. Develop and maintain good public and community relations.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

The spread of fire and smoke to adjoining areas or throughout the building can be partially controlled by incorporating certain architectural elements and design features. Some examples include the use of non-combustible and fire-resistive construction and finishes; automatic ventilation shut-down in the event of a fire; compartmentalizing or separating spaces such as collections reserves and high-hazard areas into fire-rated areas; installing fire blocks and barriers in attics and in concealed spaces and voids under floor boards, above ceilings, behind walls, etc.; stopping open spaces around current or removed plumbing, duct work, electrical conduits, etc. in walls, floors, and ceilings; fully enclosing stairwells; and installing fire doors. If fire doors are normally kept open, they should be equipped with automatic door-closing devices that close the doors automatically when the fire alarm system activates.

Many museums have worked closely and successfully with their local fire service to improve fire safety at their institutions, and to develop measures for protecting their irreplaceable collections in the event of a fire. In many cases, and providing that the fire is controlled and life safety is not an issue, steps can be taken to protect objects from heat, smoke, soot, and water. Valuable items have been spared from certain loss and damage by evacuating them to a safe area, by covering items with waterproof tarps, by diverting the water resulting from fire fighting, and by using water mist instead of water streams when combating a fire. Take the time to develop a good relationship with your fire service, give them copies of your building plans, and conduct tours of the museum for all members of the service to familiarize them with the building's layout and systems (i.e. the location of stand pipes and sprinkler zone valves), as well as any areas that might be potential fire sources or that could present potential or unexpected hazards during fire fighting. Ensure that they have the access they require to go throughout the building in the event of a fire, have them review your fire response procedures, and involve them in fire prevention and fire response training for staff.

Fire protection equipment and systems

Active fire protection refers to installing equipment, systems, and devices that require power to function such as fire detection, fire alarm, and fire suppression systems. Whether installing a brand new system, or replacing an existing one, use a fire protection specialist who is experienced in designing systems for heritage or clean room facilities and who will work with you to ensure that your fire protection objectives are met. While the cost of professionally designed, installed, maintained, and monitored fire protection may seem large, the cost of not installing them could be even greater.

The fire protection specialist will assess what system to use (to protect life safety only, building and contents, collections, all, etc.); what hazards they are protecting against; the construction, size, and configuration of the structure and the spaces within it; the actual or intended use of the spaces being protected; available water supply and pressure; and much more. For small to mid-size institutions, conventional systems that are simple, reliable, and economical to install and maintain, will suffice. Larger institutions with more complex requirements will require more complex systems. As an example, medium-size institutions may only require a basic control panel that will indicate that a device has activated somewhere, while larger institutions will require highly sophisticated control panels that precisely identify which device has activated, as well as performing other functions.

All systems should be designed and installed according to applicable codes and standards. Use the best quality components you can afford; often the difference in cost between quality is marginal, and the savings not worth the difference in value. Depending on the size and resources of an institution, systems will be monitored by an external monitoring firm, or directly by the local fire department if the service is available in your community. Larger institutions may have in-house staff who monitor their systems, and may also have a backup power supply in the event of power loss. Once installed, systems need to be inspected, tested, and maintained by a competent person and in accordance with applicable codes.

Automatic fire detection

While smoke alarm devices may alert people in the area to danger and to prompt the immediate evacuation of the building, they are inadequate for protecting cultural property. That is because most museum buildings are unoccupied for much of the time. Unless someone is present to hear the alarm and call the fire department, a fire may grow and spread rapidly and undetected before someone notices the fire and contacts the fire service.

Fire detection and fire alarm systems can range from basic to complex systems that identify which detection device has been activated, and which perform a number of secondary functions such as shutting down air circulation systems, closing smoke dampers in duct work, releasing door-holding devices on fire doors, notifying a 24–7 monitoring service, and initiating the activation of some type of automatic fire suppression system (consult Vignette 2).

There are two main types of fire detection — smoke detection and heat detection. Because smoke detectors are designed to detect fire in its earliest stages, they are recommended throughout, except in dusty or smoky areas where smoke detectors would be prone to false alarms.

As mentioned above, be sure to consult with a fire protection professional to ensure that each area of the building is protected with the most effective type of detection for that space and to reduce the chance of false alarms. When placing detectors, it is also crucial to take into account air currents created by ventilation systems or open windows, any obstruction, or other factors that may affect the effectiveness of the units.

Smoke detection

Smoke detectors are devices that detect visible or invisible particles of combustion.
There are mainly two types: photoelectric and ionization. Photoelectric detectors are most effective for smoldering fires, which produce large smoke particles, while ionization systems provide a quicker response to high-energy flaming fires, which produce large quantities of small smoke particles. Combination ionization–photoelectric detectors, known as "photo–ion smoke detectors," can be installed where protection from both types of fire is desired. Photoelectric detectors have become more popular in recent years not only because they offer substantial faster response in detecting low-energy (smoldering) fires, but also because they may equal or surpass ionization detector response to flaming fires when a fire is not close.

Air-aspirating smoke detectors are available that provide very early detection by means of drawing air into a detection chamber through a small tube, and analyzing the air for smoke. Because of its high sensitivity, air-aspirating detectors are advantageous for protecting items of very high value. And because only the tube opening is visible, they are also suitable where conventional detectors may be visually intrusive, for example among decorative moldings and other building features. However this type of detection is more expensive.

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Because both heat detectors and automatic sprinkler systems respond to heat and not to smoke, smoke detection is important in order to minimize smoke and soot damage resulting from slow-growing, smoldering fires (consult Vignette 3).

Heat detection

There are generally two types of heat detectors: fixed-temperature and rate-of-rise. Fixed-temperature heat detectors activate when a room's temperature reaches a predetermined level — usually between 57–75° C, while rate-of-rise detectors activate when the rate of temperature increase exceeds a predetermined value, typically around 7–8° C.

Because heat detectors do not detect fire in its earliest stages, they do not provide the same level of protection as smoke detectors do and should, therefore, only be used in those few areas where smoke detectors would likely cause a false alarm regularly — such as in dusty environments — or in areas where fast flaming fires would be more likely to occur. Heat detectors are best suited to protect dusty or confined spaces such as garages, attics, crawlspaces, and unheated areas where the temperature may drop below smoke detector ratings.

Fire suppression: General

In the event of a fire, early detection and suppression is essential if damage and loss are to be minimized. In most situations, water is still the most widely used fire extinguishing agent: used in fire hoses, sprinklers, water mist systems, and some portable extinguishers. It is abundant, effective, and inexpensive. Water has the ability to cool and to displace the oxygen supply. Where large quantities of water are required, a dependable water supply and water pressure are needed to support the use of fire hoses and, to a lesser degree, sprinkler systems.

Gaseous fire suppression systems are available for more specialized applications.

Following is a brief description of the more common types of fire-suppression equipment and systems for use in heritage institutions.

Portable fire extinguishers

Portable fire extinguishers are generally required by code. In the hands of trained individuals, they can be an effective tool in extinguishing small, contained fires.

It is important to select the correct type of extinguisher for the type of fire. If the wrong type of extinguisher is used, it could be ineffective, or even dangerous, in combating a fire. As an example, a water-based extinguisher used on a live electrical fire could result in a serious electrical shock to the person attempting to extinguish the fire. If used on a flammable liquid or grease fire, the water could cause the fire to spread. The type of extinguisher chosen for a certain area should be based on the expected type of fire for that area.

The four main classes of fires and extinguishers used in museums are:

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

- **Class A – common combustibles**
- **Class B – flammable liquids**
- **Class C – energized electrical**
- **Class D – combustible metals such as magnesium and sodium**

Many institutions have standardized their extinguishers to facilitate use and training. Class-ABC, multi-purpose extinguishers are now often used throughout a building on the advice of the fire department, thereby eliminating the risk of someone using an inappropriate agent.

Consult your local fire authority or advisor to determine which type of extinguisher is most appropriate for each area of your institution. Portable extinguishers are generally installed near exits. They should be mounted on approved brackets, inspected visually monthly, and maintained annually.

Some institutions prefer not to train their staff in how to use their portable extinguishers in order to discourage their use in the event of a fire. The main argument is that staff should sound the alarm, call the fire department (or equivalent fire service), and evacuate the building, allowing the fire department to extinguish the fire. While life safety always comes first, and no one should ever endanger their own life or the lives of others by extinguishing a potentially hazardous fire themselves, there may be situations where they need to use an extinguisher; for example, if the fire is blocking their exit. In addition, there may be situations where using an extinguisher on a small, contained fire can quickly and safely extinguish the fire before it has a chance to spread.

To operate a portable extinguisher, remember the word PASS. Holding the extinguisher with the nozzle facing away from you:

- **P** – Pull the pin.
- **A** – Aim at the base of the fire.
- **S** – Squeeze the lever slowly and evenly.
- **S** – Sweep the nozzle from side to side.

Unless staff is trained in the proper and safe use of portable extinguishers, there is the possibility that the units will become little more than expensive doorstops (consult Figure 9), or objects on which to hang coats.

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Figure 9. An un-mounted fire extinguisher being used to prop open a door.

Proper training of staff in emergency response can make a difference, especially in a life-threatening situation.

Automatic fire suppression

Sprinkler systems

Automatic sprinkler systems consist of a network of fixed pipes connected to a water source, with sprinklers installed at intervals along the pipes designed to discharge water at a pre-set temperature. According to the Fire Sprinkler Network, automatic fire sprinklers have been in use in the United States since 1874, and even today are widely recognized as the single most effective method for fighting the spread of fires in their early stages — before they can cause severe injury to people and damage to property.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Figure 10. Fire sprinkler head: This head has glass bulbs filled with fluid that expands and breaks when heated. A sprinkler system is an effective and relatively inexpensive means of saving lives, property, and collections.

Sprinklers (Figure 10) are ready to respond rapidly anytime of the day or night, and are unaffected by adverse traffic or weather conditions, or by dense smoke and toxic fumes. According to some experts, an automatic sprinkler system is the single most important fire-safety system a cultural property can have. A properly designed, installed, and maintained system can overcome deficiencies in risk management, building construction, and emergency response, and provide enhanced flexibility of building design.

Because most museums contain large quantities of irreplaceable and highly combustible materials and fires can grow and spread rapidly, automatic fire suppression such as sprinkler systems throughout is highly recommended in order to control — and even extinguish — fire in the time that it takes for the fire department to arrive and to set up to extinguishing capacity. Many institutions feel that they are well protected by their proximity to the local fire service and, therefore feel that they do not need automatic fire suppression. However, in addition to the potential delays and problems noted above, there is also the possibility that the fire service may be out on another call. With a sprinkler system, fire protection is in place at all times. Not surprisingly, institutions that have suffered the greatest fire losses were not equipped with sprinklers. Museums protected with sprinklers typically had comparatively minor damage and loss.

Many collection-holding institutions are reluctant to install sprinklers due to the fear of exposing their collections to the potential risk of inadvertent water damage. In fact, accidental discharges and leaks due to manufacturing defects are relatively rare. In addition, damage from sprinklers is generally far less than from high-powered fire hoses used for fire fighting. Water discharge from sprinklers is approximately 100 litres per sprinkler per minute dispersed as a gentle "rain," versus the discharge rate of approximately 500–1,000 litres per hose per minute, discharged under high pressure.

Other institutions argue that installing sprinklers is too expensive. Unfortunately, many museums unprotected by sprinklers have ended up paying twice: once for the costs of recovery and rebuilding following a fire and again for installing a sprinkler after the fact! In most cases, the cost of the sprinkler system was the lesser of the two costs.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Where aesthetics is important, for example in historic house museums, less visually intrusive sidewall or recessed sprinklers can be installed, with covers made to match the surrounding wall or ceiling. However, bear in mind that matching the colour must be done by the manufacturer. It is against code to paint over or otherwise tamper with sprinklers as this could effect their operation.

While total flooding sprinkler systems are available for industrial spaces, they are not generally used in cultural facilities. Typically, only those sprinklers that are directly affected by the fire will activate. Most fires are brought under control using 1–4 sprinklers.

For institutions located in seismic areas, it is important that sprinkler systems be installed using seismic bracing and other features.

In general there are three main types of sprinkler systems: wet pipe; dry pipe; and pre-action systems. Following is a brief description of each of these systems, and some of their advantages and disadvantages.

Wet pipe system

In a wet pipe system, the piped water system is kept under pressure and uses heat-actuated sprinklers. The sprinklers affected by high heat activate individually to suppress the fire. In most situations, a standard wet pipe system is highly recommended because it is reliable, easy to maintain, relatively inexpensive, and is kept fully charged and ready to activate, responding quickly. The main disadvantage with a wet pipe system is that accidental water damage may occur; however, this is very rare and the risk may be reduced. For example, if there is the risk of sprinkler heads being knocked (i.e. by people, cabinets, forklifts, etc.), they can be installed in an upright, sidewall, or recessed position rather than in the standard pendant position, or pendant heads can be fitted with protective cages.

Dry pipe system

In a dry pipe system, the piped system is filled with pressurized air instead of water, which is held behind a valve. When a sprinkler activates, the air is released from the pipe, opening the valve and releasing water into the pipes and out of the sprinkler. Unfortunately, dry-pipe systems are prone to corrosion and scale build-up in the pipes due to condensation and from residual moisture after required testing, making them less reliable than wet pipe systems. As are pre-action systems, they are more complicated, more expensive, more difficult to maintain, and are slower to discharge. Dry pipe systems are mainly used in spaces such as loading bays that are subject to freezing.

Pre-action systems

In a pre-action system, water is held behind a valve as with a dry pipe system, but requires the activation of a fire detection system to open the valve and release water into the pipes. Once this happens, the system is now ready to function like a wet pipe system.

Many institutions have installed pre-action systems instead of wet pipe systems in order to reduce the risk of inadvertent water damage in collection areas due to accidental discharge, or to leaking pipes or sprinkler heads. However, while this feature is indeed a benefit in areas containing highly valuable water-sensitive collections, pre-action systems are not without their problems and disadvantages, for example:

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

- This type of system takes longer to reach discharge capacity, allowing the fire to spread during this time and requiring more heads to activate, resulting in more water damage.
- Pre-action systems are more complex than conventional wet pipe systems, with the increased risk of something going wrong. As an example, a problem with the fire detection system could affect the proper operation of the sprinkler system.
- As in the case of dry pipe sprinklers, because the pipes are filled with air, moisture in the pipes could result in corrosion and scale build-up and affect the proper operation of the system.
- Because of their complexity, pre-action systems are more expensive to install and maintain than their wet pipe counterparts.

On/off systems are available in which the activated sprinklers turn off automatically when the room temperature falls below a set point, and will re-activate should the fire re-ignite. However, these systems are complex and expensive. In most urban centres, the fire service will generally arrive before the affected area has even cooled down enough to shut off the system. Therefore, these systems offer few advantages to most heritage institutions.

Regardless of the type of sprinkler system, all systems should be: designed by experienced professionals;, manufactured by a reputable firm using high-quality materials;, installed in conformance with NFPA 13: Standard for the Installation of Sprinkler Systems; and tested and maintained annually by competent personnel to keep them in good working order.

Water mist system

A relatively new water-based fire suppression system has been developed whereby small quantities of water are released under high pressure as a fine mist. This effectively cools and controls a fire using approximately 10% the amount of water discharged by a conventional sprinkler system, resulting in less water damage.

Because water in a fine spray form does not conduct electricity the same way a stream of water does, it can be used on live electrical equipment. Where a clean water discharge is critical, stainless steel piping and distilled water can be employed.

While water mist systems were initially designed mainly for marine applications, they are being seen more and more in museum and archival facilities, and in heritage buildings. These systems are particularly practical for historic buildings undergoing retrofits because smaller diameter and flexible piping can be used in narrow and awkward spaces where the installation of traditional sprinkler systems may be difficult or impossible without disrupting original construction.

Water mist systems can be installed plumbed to a permanent water supply or connected to a series of water tanks stored nearby. This latter scenario might be appropriate in situations where the water supply is not dependable, or for seasonal institutions that are unheated during the winter. Because water is not kept in the pipes, areas of the building subject to freezing can still be protected providing the water tanks themselves are kept from freezing.

While this type of fire suppression system shows great promise for heritage institutions, it is still quite a new technology and, as such, there may be problems finding contractors who are familiar and experienced in installing it. However, this should become less of a problem as these systems become more common.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Automatic gaseous suppression systems

Since the demise of CFC-containing Halon gas for environmental reasons, several so-called "Halon alternatives" have been developed that some museums are installing in collection areas as an alternative to water-based systems. However, for those institutions that currently have Halon systems, there is no true replacement "drop in" system because new piping is generally required.

Unlike sprinkler heads that discharge individually, gaseous fire suppression systems are total flooding systems whereby the agent discharges from all the nozzles within the protected space simultaneously in order to reach the required concentration levels necessary for effective extinguishment.

Gaseous fire suppression systems offer the advantage of no water damage to collections. However, as with other types of suppression systems, there are disadvantages, restrictions, and issues associated with gaseous systems that should be considered when choosing an automatic suppression system. For example:

- These systems are primarily designed for well-sealed spaces such as storage vaults. Their effectiveness will be compromised if the door to the protected area is propped open, if there are any openings through which the gas can escape, or if the ventilation system and smoke dampers have not shut down.
- Some systems require venting to the outside to allow displacement of room air.
- Once the gas has discharged and dissipated, the area is no longer protected until the gas is replaced and the system is recharged. As a result, a sprinkler system backup is highly recommended.
- Gaseous systems are typically more expensive than sprinkler systems.
- Gaseous systems are quite complex, and require everything to function properly in order for the system to operate effectively.
- Design, installation, maintenance, and servicing by competent personnel of systems in institutions located in more remote areas or in smaller centres, may not be practical, economical, or even available.

Following is a brief description of several gaseous agents found in Canadian museums.

Inergen

Inergen is an inert gas composed of nitrogen (52%), argon (40%), and carbon dioxide (8%). Although this system extinguishes fire by reducing the concentration of oxygen below that which will sustain combustion, the concentration of oxygen remains above the lower limit required for breathing, making it safe for people. Being completely inert and non-residual, it is also safe for collections. Discharge of the agent does not restrict visibility, nor does it result in a large temperature drop as with some other systems.

Inergen discharges under high pressure and requires heavy-duty hardware that will withstand the pressure. Inergen also requires a larger number of storage cylinders of agent than do some other systems to protect the same size area, which could result in space and weight implications.

While the cost of the hardware is generally higher than for some other systems, the agent is less expensive and is easier to replace.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

FM 200

FM 200 is a halocarbon gas that extinguishes fire by means of heat absorption. While there is no risk of oxygen reaching a dangerously low level, there are still some health implications because harmful chemicals are released during discharge.

FM 200 is stored as a liquid and is discharged as a gas. Because it requires a relatively limited volume of stored liquid, it is an option where only limited storage space is available.

Some disadvantages of FM 200 include some global warming potential and the formation of some decomposition products that could affect collections. While the system is typically less expensive to install, the cost of the agent is greater than for inert gas agents.

NOVEC 1230

While NOVEC 1230 total-flooding, fluorinated ketone, clean agent fire suppression has been installed throughout Europe for a number of years, it is relatively new to North America, and especially to Canada. Shipped and stored as a liquid, it vapourizes upon discharge and extinguishes fires by absorbing heat. NOVEC 1230 fluid has the lowest atmospheric lifetime (i.e. 5 days versus 33 years) of current halocarbon fire suppression agents, the greatest margin of safety for use in occupied spaces, and has zero ozone depletion potential.

Fewer tanks of the agent are generally required to protect the same volume of space as some other gaseous systems. However, while less storage space is required, the tanks must be located within 20 to 30 m of the space to be protected. As with most gaseous systems, NOVEC 1230 discharges at a high pressure.

NOVEC 1230 eliminates water or chemical damage to computers, electronics, books, artwork, etc. In demonstrations, items immersed in the agent have been removed dry and undamaged.

The above three gaseous systems are briefly summarized in Table 2.

Table 2. Summary of clean agent gaseous fire suppression agents.

System	Comments
General	• No water damage • Only for use in well-sealed spaces • In some cases, considerable space required to store tanks • Discharge pressure can be damaging • Installation and servicing by competent personnel may be a problem away from major centres • Sprinkler system backup recommended in the event of incomplete extinguishment by the gaseous system
NOVEC 1230	• A fluoroketone agent • Extinguishes fire by absorbing heat • Requires fewer tanks with a smaller footprint to protect the same size space • Potential to produce decomposition gases under certain conditions

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

	• Less expensive than some other gaseous systems
Inergen	• A totally inert gas consisting of nitrogen, argon, and carbon dioxide • Has the highest discharge pressure and requires more storage space for the storage of the cylinders.
FM 200	• A hydrocarbon gas • Extinguishes fire by absorbing heat • The closest system to a "drop-in" replacement system for Halon 1301 • Requires fewer storage tanks than some other systems • Produces decomposition gases

As with any other fire protection systems, consult a fire protection engineer to determine if a gaseous fire suppression system is appropriate for your institution.

Vignettes

Vignette 1.

On the night of August 19,1980, the Miner's Museum of Cape Breton (Figure 7) in Glace Bay, Nova Scotia, suffered a catastrophic fire. While the cause of the fire is not known to museum staff, it may have originated from either smoking that took place during an evening concert in the adjoining auditorium, or from vandalism (remains of Molotov cocktails had been found on the premises in the weeks before the fire). The structure was a modern non-combustible and fire-resistive construction, and included an auditorium, and a National Exhibition Centre for displaying travelling exhibits. There was no monitored fire alarm system or automatic suppression system, nor was there a fire door leading to a coal mine shaft located underneath the museum. Former coal miners served as guides, and the mineshaft was popular with visitors.

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Figure 11. Miner's Museum, Glace Bay, Nova Scotia.
"Before" photograph, taken on August 18, 1980.

On the night of the fire, a concert featuring the Men of the Deeps took place in the auditorium. As was the custom at the time, smoking was permitted. Approximately one hour after the end of the concert, a passerby noticed flames shooting from the clerestory windows of the museum's library and called the volunteer fire department. The fire service arrived quickly and additional support was brought in from nearby Sydney. The fire burned for three nights and two days, resulting in the loss of approximately 70–80% of the building and the collections (Figure 8). Because the main priority of the fire service was to prevent the fire spreading to the coal seams in the mineshaft, the remainder of the museum was sacrificed.

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Figure 12. Miner's Museum of Cape Breton, Glace Bay, Nova Scotia. "After" photograph, taken three days later.

If the museum had had a monitored smoke detection system, the fire might have been detected before the onset of flames, while an automatic sprinkler system may have controlled — and possibly extinguished — the fire even before the fire service arrived on the scene, resulting in minor, not serious loss.

With the strong support of the community, the museum has since been rebuilt, and includes a monitored security system, video surveillance system inside and out, exterior security lighting, a monitored fire alarm system, both smoke and heat detection, an automatic wet pipe sprinkler system, and metal fire doors protecting the mine entrance.

Vignette 2.

One night in August 1992, a fire resulting from arson broke out in a main floor room of the Billings Estate National Historic Site — a historic house museum — in Ottawa, Ontario (Figure 13). Although the museum was located in a visually remote site set back from both pedestrian and drive-by traffic in a residential neighbourhood, the fire was quickly detected by the monitored smoke detection system, resulting in a rapid response by the fire department.

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Figure 13. Billings Estate National Historic Site: Exterior view. The boarded-up windows indicate the location of the fire within the museum.

In the months preceding the fire, plans had begun to install an automatic sprinkler system. The director of the museum had also met with the fire department to discuss her concerns regarding potential water damage in the event of a fire. This discussion turned out to be fortuitous! Because the fire occurred during non-working hours, life safety was not an issue. As well, because the fire department arrived while the fire was still relatively contained and controllable, the fire fighters were able to enter the structure using carbon dioxide fire extinguishers while the hoses were connected to the standpipe. Once connected, the blaze was fought using water spray rather than streams of water.

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Figure 14. Billings Estate National Historic Site:
Interior view of fire site. Monitored smoke detection and a rapid response by the fire service resulted in serious damage being contained to only one room in the after-hours fire in this historic house museum.

Although there was fairly extensive soot damage throughout the museum, as well as some heat and flame damage in the room where the fire originated (Figure 14), there was virtually no water damage to the house or to the collections. The museum has since installed a sprinkler system.

Vignette 3.

During renovation and construction of new and existing permanent exhibit galleries at the then Saskatchewan Museum of Natural History (now the Royal Saskatchewan Museum), Regina, Saskatchewan, a smoldering fire began when the heat released by the curing of a two-part foam insulation compound became trapped while in contact with modern fire-resistive construction materials, resulting in the development and the spread of heavy smoke. Because the smoke detectors in the project area had been covered to prevent dust contamination during renovations, detection of the fire was delayed until a smoke detector elsewhere in the museum activated. In addition, the fan of the museum's air handling system failed to shut down, allowing smoke to spread rapidly throughout the facility.

Although response time by the fire department was rapid, the accumulation of thick smoke and the lack of a zoned fire alarm system, prevented the fire fighters from locating the source of the fire quickly, resulting in a thick layer of soot deposited throughout the museum, including the permanent galleries and dioramas. Fortunately, most of the museum's collections had been removed and relocated to an off-site storage facility before the renovation work.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Statistics indicate that construction and renovations are extremely high-risk activities for museums. In this case, had the smoke detectors been rendered operational at the end of each working day, and had a fire watch been implemented during the construction work period and for several hours afterwards, the fire may have been detected sooner and extinguished before much damage occurred.

References

National Parks Service (NPS). **Museum Handbook, Part 1. Museums Collections. Web** Edition. Appendix M, "Management of Cellulose Nitrate and Cellulose Acetate Films." (PDF Version, 208 KB) 2001.

Key readings

- Artim, Nick K. "An Introduction to Fire Detection, Alarm, and Automatic Fire Sprinklers." **Preservation of Library & Archival Materials**. Emergency Management Technical Leaflet 2. Andover: Northeast Document Conservation Center, 1999. Leaflet updated 3/17/04.
- Canadian Conservation Institute. **Fire Protection Issues for Historic Buildings**. CCI Notes 2/6. Ottawa: Canadian Conservation Insitute, 1998.
- Canadian Conservation Institute. **Museum Fires and Losses**. CCI Notes 2/7. Ottawa: Canadian Conservation Institute,1998.
- Canadian Conservation Institute. **Automatic Sprinkler Systems for Museums**. CCI Notes 2/8. Ottawa: Canadian Conservation Institute, 1998.
- National Fire Protection Association (NFPA). NFPA 909: **Code for the Protection of Cultural Resource Properties - Museums, Libraries, and Places of Worship**. Quincy, MA: National Fire Protection Association, 2005 Edition.
- NFPA 914: **Code for the Protection of Historic Structures**. Quincy, MA: National Fire Protection Association, 2007 Edition.

Thanks to the Centro Nacional de Conservación y Restauración in Chile, the Canadian Conservation Institute's web resource Agents of deterioration, translated into Spanish by ICCROM, is now available free of charge. Intended for curators and conservators, the resource identifies 10 primary threats specific to heritage environments.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Water

David Tremain

Introduction

This section deals with water in its liquid form, but also includes dampness resulting from condensation and rising moisture. (Visit "Incorrect relative humidity" for information on water vapour.) It identifies the major issues with incidents that cause water damage in collections, and provides strategies to prevent or minimize any occurrence. This section does not describe recovery strategies after damage has taken place.

Table 1. Factors leading to water damage.

Natural	Technological/Mechanical	Accidents
• Rainstorm • Windstorm • Hurricane • Sleet, hail, ice storm • Flash flood • Slow rising flood • Tsunami (if located in a coastal seismic zone) • Spring melt or run off • Ice jam • High water table • Located by or close to a body of water (river, lake, or dam)	• Sewer failure/back-up • Sprinkler system malfunction • Broken water line (may be caused by freezing or construction) • Leaking roof • Leak from heating system, ventilation system, or air conditioning system (HVAC) • Overflowing sinks, toilets, drains (that may be blocked or unable to cope) • Blocked eavestroughs • Careless use of water during special events, social functions, etc. • Use of water during construction and renovations • Poorly/improperly insulated building • Storm drains/sewers (that are unable to cope)	• Water used in cleaning up chemical spills • Water damage due to fire (sprinkler system discharge or/and fire hoses)

Water damage is a depressingly regular occurrence in heritage institutions. It can result from natural occurrences, technological hazards, or mechanical failures. However, the majority of water-related problems in cultural institutions are the result of accidents or neglect. Many custodians underestimate the likelihood and effects of sporadic events such as water leaks. There is a tendency to use basements for collection and archival storage and to leave boxes of material on the floor, perhaps only "temporarily." Many containers for paper documents and small artifacts purchased by museums are acid-free, but few institutions consider acquiring watertight boxes made from fluted polypropylene. Some of the factors and events typically leading to water damage are shown in Table 1.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

A great many of the materials that museum objects are made of are highly susceptible to contact with water and can be severely damaged by even brief contact, while others may be exposed to water for longer periods without harm. This situation is complicated by the combination and range of materials that may comprise each object. In addition, the vulnerability of individual objects to water can be affected (i.e. increased) significantly by the state of the degradation of the materials. For example, a badly degraded, acidic wood pulp paper will absorb more water, leading to heavier water staining and "tide lines." Approximate types of damage to some common museum materials are shown in Table 2.

Table 2: Damage of some museum materials caused by water

Material	**Damage caused by water**
Bone products	Possible cracking and distortion, staining, degradation of collagen, teeth (skulls) loosen, physical weakness (depending on how initially cleaned)
Books	Softening, distortion, running of inks and dyes, staining; softening, distortion and subsequent hardening (on drying) of leather bindings
Ceramics	Porous surfaces stained, salts or patina (if archaeological) lost
Glass	Existing glass "disease" stimulated
Keratins	Feathers matted, dyes run
Leather	Vegetable-tanned objects shrunk, distortion, staining, degradation of collagen and turning into gelatin
Metal	Reactive (e.g. ferrous) metals corroded, existing corrosion stimulated
Paintings	Delamination, sizes and water-soluble glazes dissolve, varnishes blanch, wooden panels distort, frame or stretcher joints loosen, canvases distorted (cockling)
Paper	Softened, inks run, staining, tide lines, distortion (cockling)
Photographs	Softening of the paper, gelatin swells, staining, emulsion lifted, dyes run
Plant materials	Shrinkage, distortion, staining, solubilization of adhesives
Plastics	Porous surfaces stained
Shell	Porous surfaces stained, efflorescence
Stone	Porous surfaces stained
Textiles	Dyes run, staining
Wooden objects	Shrinkage, distortion, staining, splitting, delamination, blanching of varnishes, joints loosen, swelling
Any organic objects	Mould

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Control strategies

This section follows the strategies of **Avoid, Block, Detect, Response**, and **Recover/Treat**. However, the fifth strategy, **Recover/Treat**, is not covered in detail because it deals with specific procedures following water-related incidents and is, thus, beyond the scope of this resource.

Avoid

Location of building

Avoidance of water hazards starts with the location of the building. In almost all cases, the building location is fixed and, thus, the only ways to avoid location-related hazards are:

- If it is new construction, do not select a building site close to a body of water, or in a flood plain. Such is the case with Old Fort William in Thunder Bay, Ontario, which experienced major floods in 1977, 1982, 1983, 2003, and 2006 (Figure 1 shows the level of the water during the 1977 flood). Implementing this strategy would only be possible during the site selection phase of new building planning.
- Raising (new or an existing building) the structure above the projected flood line. This requires extensive engineering and is often very costly.
- Relocating an existing building to a safer area (i.e. on a higher ground foundation). However, relocating buildings is costly and logistically difficult, although it has been done for historic houses on many occasions. Recreated historic sites, such as King's Landing in New Brunswick, is one example.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Figure 1. Old Fort William during the 1977 flood.

Design issues

The building envelope must maintain water-tightness in order to avoid external sources of water. So consider the following when a new facility is being designed:

- Do not incorporate standing water into the building design (e.g. ornamental fountains and reflecting pools).
- Avoid designs that incorporate:
    - flat roofs, because of their tendency to drain poorly and accumulate snow and ice. However, depending on the size of the building, this is difficult to avoid. Cost is also a factor if deciding on another type of roof; and
    - large glass surfaces such as skylights, domes, and large windows facing the prevailing wind that will leak after heavy precipitation.

Where none of these solutions is feasible, it is necessary to avoid all potential sources of water, both external and internal.

Strategies for storage and display areas

- Avoid displaying, storing, or examining objects near sources of water, such as:
    - in the basement or attic. If basement storage is unavoidable, raise objects at least 10 cm off the floor; and
    - under pipes, air conditioners, or other sources of water. If storage under pipes is unavoidable, try to position shelving in between pipes.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

- Ensure pipes are well-insulated against freezing in winter.
- Seal all openings around pipes to prevent water leaks.
- Avoid:
    - using carpeting in the stacks or storage areas. If carpeting becomes wet, it may absorb a large amount of water and greatly increase the humidity level;
    - placing shelving or objects against walls because water from above may run down the walls;
    - placing objects on or against uninsulated exterior walls or near windows because there is the potential for damage from leaks or condensation; and
    - locating janitors' sinks in or above collection areas.
- Store collections separately so that they will affect each other as little as possible if they become wet (e.g. store coloured textiles separately from whites).

Protocols for construction or renovation

Water problems caused by accidents during construction or renovations can be avoided by supervising contractors, and by ensuring that they adhere to explicit guidelines. A construction accident at the Chicago Historical Society in 1986 where a water main was severed resulted in considerable damage to collections, and almost caused loss of life. Points to consider in forming such guidelines are:

- providing orientation for contractors to ensure that they understand the sensitivity of the material they will be working around;
- controlling sources of water (e.g. sites for mixing cements and plasters);
- installing protective shells during construction/renovations;
- identifying water control valve(s) (domestic and sprinkler systems);
- taking special care when:
    - inspecting or servicing sprinkler systems; and
    - working or carrying out renovations close to sprinkler heads;
- relocating or covering objects near work being carried out on plumbing; and
- having incident response procedures in place (e.g. who will do what if a pipe leaks or bursts, a sprinkler head is damaged, etc.).

Building maintenance strategies

Many water problems, particularly in smaller museums or historic houses, are caused by poor maintenance, or the lack of it. A routine maintenance program should be carried out to either prevent or mitigate the effects of water, such as:

- developing a checklist to ensure that the building's perimeter is visually inspected (external/internal). Some potential building deficiencies or problems are:
    - roof leaks;
    - chimney leaks;
    - faulty or loose roof shingles and flashings;
    - leaking windows and doors;
    - missing chinking in log walls;
    - blocked eavestroughs;
    - poor drainage or grading;

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

    - cracked foundations or parging;
    - footings that are too small;
    - vegetation too close to the building (i.e. trees, vines, shrubs); and
    - splits or cracks in structural columns and supports;
- ensuring a staff member (or contractor) is specifically assigned to carry out routine maintenance of the building and correct deficiencies;
- installing eavestroughs and downspouts to drain water away from the building, and having a scheduled program in place to inspect and clean eavestroughs and downspouts to prevent blockage from leaves or debris;
- using landscaping to ensure there is a sloping away from building foundations to drain away water;
- not allowing ice build-up on roofs in the winter. Installing heating wires in vulnerable areas to reduce ice and snow; periodically inspecting to ensure the system is operational; using professional roofers for ice and snow removal;
- ensuring the roof is in good condition (e.g. no loose tiles or shingles, no holes, etc.) and taking corrective actions in a timely manner;
- installing a sump pump and including a battery back-up system in the event of a power failure if flooding is a recurrent problem; and
- carrying out daily inspections at the end of the day before closing to ensure there is no running water left unattended, or toilets overflowing.

Strategies for storage and display

- Use water-resistant storage containers.
- Ensure that drawer units are watertight and that small objects in storage are enclosed in plastic bags or boxes.
- Use display case covers wherever possible; they will at least prevent dripping or spraying water from falling on objects.

Block (mitigate)

Where a direct threat cannot be avoided, having a preventive program in place that anticipates the problem and includes procedures or measures for mitigating its effects can be effective. These include:

- being aware of meteorological conditions (e.g. weather warnings, flood warnings, etc.) in the institution's locale by monitoring the weather networks, news media, the Internet, etc.;
- if the building is in an area prone to flooding or high precipitation, ascertaining the highest level for floodwater (such information is often kept on file by municipal authorities);
- keeping informed of decisions by water conservancy authorities to raise/lower water levels;
- having sandbags ready to place around doors and below-grade windows when bad weather is predicted;
- being prepared to tape or board up windows and doors;
- being prepared to move collections to higher levels within the building or to a temporary safe location(s);
- assembling equipment such as pumps, wet-dry vacuums, mops and squeegees ("response cart" or a designated storage area) for dealing with such emergencies, or at least know where the equipment can be acquired in a hurry.
- placing staff on full alert; and

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

- placing tarpaulins or industrial polyethylene sheeting over any parts of the building where water might seep in during a rainstorm.

Table 3. Emergency supplies

Basic supplies	**Substantial supplies**	**Full contingency supplies**
• polyethylene sheet (roll) • mops • bucket • squeegees • rubber gloves • rubber boots • hardhats • flashlight and batteries • blotting paper • unprinted newsprint (roll) • terry towelling • freezer paper • sponges	Basic suppliers + • wet/dry vacuum • industrial fans • extension cords • step ladder • carts • dehumidifiers • tools	Substantial supplies + • crash carts • freezers • access to freeze driers • contingency room

Detect

The first priority of detection is to conduct a risk assessment to identify the existing level of risk. This should be coordinated with an inspection of the building's exterior and interior and its collections for signs of water. Regular inspections should follow. These can be integrated into routine housekeeping and monitoring tasks.

Detection can be in three stages:

1. The visible presence of liquid water from a flood or leak, which warrants immediate action (see "Response").
2. Signs of insidious water damage on both the building and the objects that indicate a water problem that should be identified and traced back to source, such as:
    - efflorescence on stone, concrete, or brickwork on the building exterior;
    - plant growth on the building exterior, particularly mosses and algae;
    - efflorescence on stone, concrete, brickwork, and plaster on the building interior;
    - algal and fungal growth on interior walls;
    - peeling paint (this can also be caused by poor quality paint, poor application, or high fluctuation of relative humidity);
    - excessively cool walls or floors;
    - drips and stains on walls, floors, and ceilings;
    - "tide lines" on floors;
    - external corrosion on pipe work and metals fittings attached to walls;
    - movement of floorboards
    - visual signs of mould growth or rot; odour (i.e. a damp smell); and
    - widespread damage, such as that referred to in Table 2, is an indication of water problems in the collection or storage area.
3. Indications from alarm systems or other monitoring devices of the presence of water.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Monitoring systems

Install:

- water detectors in all areas where it is suspected water could enter the building or leak from interior fittings;
- a monitored environmental system to indicate changes (fluctuations) in relative humidity;
- dataloggers; and
- recording hygrothermographs.

Response

Response procedures are initiated when an incident is detected. In general, these strategies can be devised from the results of "worst case" scenarios. Following are measures that can be taken:

Procedures for immediate response

In any response to an emergency, whether it be water or another problem, human life and safety always come first. Major floods can bring with them hazards such as:

- contaminated water (bacteria, fecal matter)
- animal or human remains (worst-case scenario, i.e. Hurricane Katrina and New Orleans flood)
- disease
- mould
- debris (brick, concrete, wood, nails, etc.)
- slippery floors (e.g. from mud, ice)
- live electrical wires or electrical devices in water
- extremes of temperature

Health and safety precautions

It should be assumed that water is contaminated until proven otherwise. Water may need to be sampled and tested for possible contamination, particularly if it is a widespread flood, such as the Peterborough flood in 2004, where water was found to be at a level 4 contamination with E-coli present. Therefore, ensure that hepatitis A and tetanus shots are up-to-date and always wear appropriate CSA- or ASA-approved personal protective equipment (PPE):

- Tyvek™ overalls
- N95 or N100 respirator
- plastic gloves
- rubber boots or bootees
- hard hat

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Procedures for controlling water

- Contain the flow of water.
- Shut the water off at the source, where possible (may involve a facilities manager or city official).
- Protect (i.e. cover, remove) any collections immediately under the source of, or in the path of, water.
- Remove standing water with wet/dry vacuums, pumps, mops, and squeegees.
- Remove any materials capable of retaining water (i.e. carpeting, drywall, upholstery).
- Maintain air circulation (fans, dehumidifiers, open windows).
- Monitor the environment and try to return it slowly to its original temperature and relative humidity.

Recover/Treat

Recover or **Treat** deals with implementing measures to prevent further damage to the affected collections, as indicated in Table 2, and, possibly, carry out conservation treatments (not discussed here). The major goal is to prevent the following:

- mould attack and subsequent damage;
- further physical damage due to drying out too quickly or too slowly, which can cause tearing, distortion, splitting, cracking, etc.;
- surfaces or objects sticking to each other;
- absorbent materials (such as paper, textiles, leather) hardening due to soaking and subsequent drying;
- accretions on surfaces from contaminants in water;
- dissolution of pigments, dyes, water-soluble adhesives, etc.;
- loss of information;
- loss of fragments from paper, paintings, ceramics, etc.; and
- loss of objects.

The efficiency and effectiveness of recovery from water damage depends on the facility's emergency and disaster preparedness. It is essential that the organization formulates and keeps current a specific plan. This will include at least the following:

- priority of the treatment specific to the collection;
- location information on all objects;
- contact tree for personnel;
- contacts for local emergency services;
- contacts for conservation advice and assistance; and
- location of supplies, equipment and facilities.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Vignettes

Vignette 1. Perth-Andover flood, New Brunswick

Figure 2. Documents and books from Perth-Andover flood air-drying. Reproduced with the permission of the Provincial Archives of New Brunswick.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

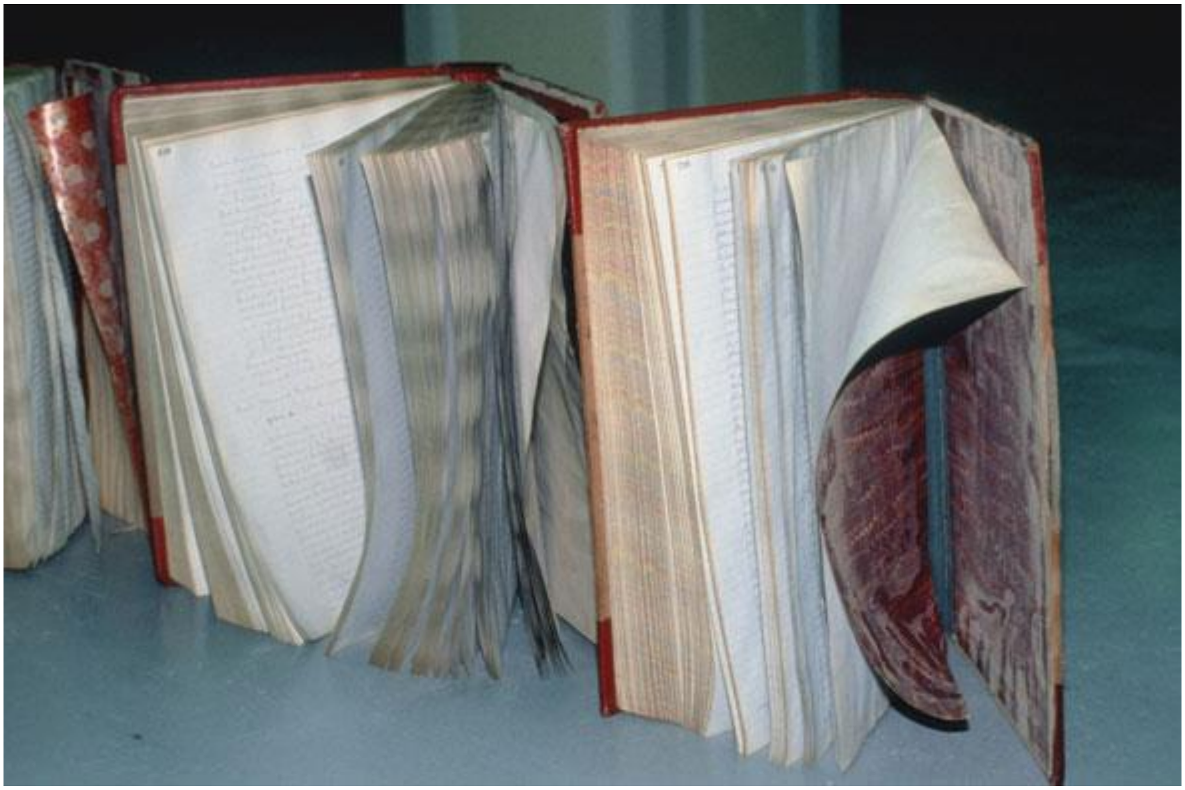

Figure 3. Detail of books air-drying. Note mud deposits on fly-leaf and paste-down. Reproduced with the permission of the Provincial Archives of New Brunswick.

During the winter of 1986–1987, there had been consistently heavy snowstorms in the area of Perth-Andover, New Brunswick. On April 1, 1987, the ice on the river began to break up, causing an ice jam to form. On the evening of the first day of the flood, the river level began to rise to the 1976 flood level mark of 78 m, and early the next morning (1:00 am), it had risen well above it. In the early hours of the morning, the New Brunswick Emergency Measures Organization issued a flood warning. The Royal Canadian Mounted Police and the local police force began warning residents in low-lying areas. The river had crept across the main street where the archives building is located, beside the St. John River and in a known flood zone. A State of Local Emergency was declared and the mayor ordered that all electrical power be turned off. The local hospital was evacuated and town residents were urged to leave their homes as soon as possible. Between 8:00 and 9:00 am, the population of the entire downtown district was evacuated.

Approximately 2 m of water reached the first floor level of buildings, including the archives building. Some of the records were stored in a vault, while others were on open shelves or in filing cabinets. Staff were able to recover all items stored in it. They relocated the microfilm and microfiche collections to a nearby motel before the water rose.

The water level peaked at 79.5 m in mid-morning on the second day (April 2), and the ice jam broke. The water receded below flood level and some residents were allowed to return to their homes.

When conservators from Ottawa and Fredericton were finally allowed to enter the archives building on the Saturday following the flood, they found various types of ledgers, court records, and land grants on linen, some of which were wet, while others were floating in the water. These were retrieved and taken,

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

along with thousands of other documents and bound material, to a provincial government warehouse outside Fredericton.

Drying this material presented a number of problems because there was neither access to freezing or vacuum freeze-drying facilities, nor other staff to assist the conservators. It was, therefore, decided to air-dry everything, using whatever absorbent materials were available (blotting paper, paper towels, rolls of Kraft paper, etc.), while circulating the air with four freestanding fans. Because there were no tables available, the documents were laid out on blotting paper on the floor until they were dry, whereupon another batch replaced them. The air-drying caused cockling and wrinkling of paper and detachment of some bindings.

Inevitably there are things to be learned from disasters, but it is necessary to resist the temptation to criticize, and to concentrate instead on learning and developing. Following are some pointers:

- Formulate a disaster plan for the facility, and ensure that it is kept up to date. This would include a system for establishing priorities in evacuating collections from the building.
- Keep a kit of essential materials, such as blotters, paper supplies, and plastic sheeting, in stock.
- Ensure access to equipment and facilities. It is not necessary to have sophisticated equipment on hand, but a network of contacts should be developed and maintained.
- Provide more effective waterproofing for objects.

Vignette 2. Cumberland Heritage Village Museum flood, Ontario

Figure 4. Water damage to furniture and wooden objects (i.e. cart wheels) after Cumberland Museum flood. Reproduced with permission of the Cumberland.

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Figure 5. Icicles hanging from chair after Cumberland Heritage Village Museum flood. Reproduced with permission of the Cumberland Heritage Museum, City of Ottawa.

The Cumberland Heritage Village Museum's storage facility is an old fire hall owned by the City of Ottawa. Objects stored in it consist mainly of domestic furniture, agricultural implements, an upright piano, a pump organ, and archival records relating to the history of the museum. City staff inspected the facility once a month during winter 2003. During one of the regular inspections, it was discovered that over 2,000 m^3 of water had leaked from a broken 3/4 in. water pipe in the roof after both furnaces had broken down. The cause appears to have been a malfunction of the roof-mounted furnace — a failure of the oil supply resulted in the furnace shutting down, thus freezing the building and causing a pipe to burst. During this flood, the outside temperature dropped to –25°C, causing the flowing water to freeze. The water had cascaded onto the objects below. It was fortunate that the building had a central drain, otherwise the water might have risen a metre or more before freezing solid. It is unknown exactly when the leak occurred, but it was thought to have been within a two-week period preceding the inspection because no one had been there in the meantime. Had it not been for the inspection, the leak would not have been discovered until much later. Due to the location of the leak, only about 15 to 20% of the storage room area was affected.

While all smaller objects had been placed on shelves and covered with polyethylene sheeting secured with Velcro, in some places the force and quantity of water had displaced the polyethylene and soaked the objects. Smaller objects, that were stored on metal racks covered with polyethylene, still in position fared well. This combination of good planning and industry saved the greater majority of this material from

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

further harm. The larger furniture and agricultural implements were soaking wet. The upholstery of some of the furniture was also saturated, and some furniture was encased in ice and had icicles hanging from it. Wood had warped and split, layers of paint had peeled and flaked off, and some veneers had started to lift. Other objects affected by the water included the paper sleeves for 78 rpm records, archival documents in coloured file folders or plastic ring binders, and some receipt books.

The greatest danger to the collection was from attack by mould. In order to speed drying of the room, and to minimize mould growing during the drying, the large vehicle-sized doors at each end of the building were raised slightly and the furnaces problems were rectified, and the furnaces were turned on. Air circulation was ensured by placing large commercial fans in the gap below the doors at one end. As soon as the furnaces were running, the polyethylene sheet was removed from the racks to ensure the greatest airflow over and around all the wooden items. In less than a week, the relative humidity was reduced to 40%. The fans were kept running until it was determined that all the objects were dried out.

Paper documents were transferred to clean, dry boxes and placed in an unheated storage building, so they froze quickly with the outside temperature being approximately –25°C. This was a stopgap measure until they could be placed in a commercial freezer facility and vacuum freeze-dried.

In view of the severity and duration of the flood, damage to the collection was not major. This can be attributed to how fast the situation was assessed, and drying and stabilization were carried out. Some painted furniture suffered losses to the finishes due to the wood swelling. Veneered wooden objects absorbed so much water that the veneer buckled and detached from the underlying frame. Pieces of furniture that stood with their feet in water had tide line stains in their finishes directly above the feet. The paper sleeves on 78 rpm records were mostly discarded.

In order to avoid a similar disaster in the future, or to be prepared for similar events, the following points should be considered:

- Formulate a disaster plan for the facility, and ensure that it is kept up to date.
- Keep a kit of essential materials, such as blotters, paper supplies, and plastic sheets, in stock.
- Ensure access to equipment and facilities. It is not necessary to have sophisticated equipment on hand, but a network of contacts should be developed and maintained.
- Install alarms or data loggers with remote read-outs, to warn of the presence of water or fluctuating temperature and relative humidity.
- Increase the frequency of cursory inspections.
- Institute regular maintenance schedules for all installations and machinery
- Provide more durable waterproofing for open shelves with large objects.

References (key readings)

- Ball, Cynthia, and Audrey Yardley-Jones, eds. **Help! A Survivor's Guide to Emergency Preparedness**. Museum Excellence Series: Book 3. Edmonton: Museums Alberta, 2001.
- Buchanan, Sally. Emergency Salvage of Wet Books and Records. North East Document Conservation Center Technical Leaflet, Emergency Management, Section 3, Leaflet 7. North Andover: NEDCC, 1999.
- Government of Canada. Flood Damage Reduction Program, on July 21, 2008.
- Government of Canada. Keeping Canadians Safe, on July 21, 2008.
- Hutchins, Jane K., and Barbara O. Roberts, eds. **First Aid for Art. Essential Salvage Techniques**. Lenox, MA: Hard Press Editions, 2006.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

- Wellheiser, Johanna, and Jude Scott, eds. **An Ounce of Prevention: Integrated Disaster Planning for Archives, Libraries and Record Centres**. 2nd edition. Maryland and London: Scarecrow Press, 2002.

Thanks to the Centro Nacional de Conservación y Restauración in Chile, the Canadian Conservation Institute's web resource Agents of deterioration, translated into Spanish by ICCROM, is now available free of charge. Intended for curators and conservators, the resource identifies 10 primary threats specific to heritage environments.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Pests

Tom Strang and Rika Kigawa

Pest organisms

Pests[1] are living organisms that are able to disfigure, damage, and destroy material culture (Figure 1).

Figure 1. Dermestid beetle larvae have eaten the decoration on this Naskapi hide mitten because the pigment binder has greatly increased the nutritional value for the larvae.

As human habitation and agricultural activities have increased, many pests have adapted to and found niches in our buildings and our undertakings. These pests have moved around the world and proliferated through trade and travel.

Microorganisms, insects, and rodents represent the majority of pests affecting cultural heritage. These three subtypes are significant risks in the north-temperate Canadian environment. Other pests, such as roosting birds, molluscs (marine borers), bats, other invasive mammals, lizards, etc., may be significant despoilers in specific locations, but are not as predominant worldwide inside collection spaces.

[1] This definition excludes human activities, which are commonly called vandalism.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

There are 830,075 described species of insects, 100,800 species of fungi, and 4,496 species of mammals (Lecointre and Le Guyader 2006). While pests are but a fraction of these species, a complete list of pests would be too large for the scope of this document. "Pest" will therefore be defined in general terms by the given subtype accompanied by some common examples; however, the control strategies will not be oversimplified.

Non-pest organisms

In nature, there are dependencies and competition among organisms. For example, "beneficial" organisms (spiders, centipedes, and parasitic wasps) prey on pests. On close observation, these non-pest organisms will be seen in collections. As with pests, their presence may also be objectionable, causing modest soiling, and indicating that a collection enclosure is not sealed properly.

Non-pest, "non-beneficial" organisms can also be found in collections (e.g. sowbugs, millipedes). They sometimes indicate a pest problem because of their association with certain environmental conditions or their association with the presence of building perforations. Their presence may be objectionable for the reasons stated above. As well, their bodies may provide food for some pest species. Therefore, controlling these organisms is usually undertaken, preferably by keeping them out.

Pest subtypes

Pests can be subdivided by biological classification or by the materials they attack. Correctly identifying pests is the first important step in learning the inherent biological limitations of each organism infecting a collection. These limitations are then exploited in order to control them. Be aware that within the pest subtypes, the materials that are attacked will vary. As well, the species within subtypes may have specialized abilities that enable them to exploit or to withstand control measures.

Microorganisms

Fungi (moulds) and bacteria are numerous and ubiquitous. Mould spores and bacterial spores can be airborne or carried along with other particulates. Bacteria are commonly brought into a collection area by contaminated floodwater or can form in standing water in buildings. Fungal hyphae are the destructive phase of mould. The actions of the hyphae stain and digest objects (Figure 2).

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

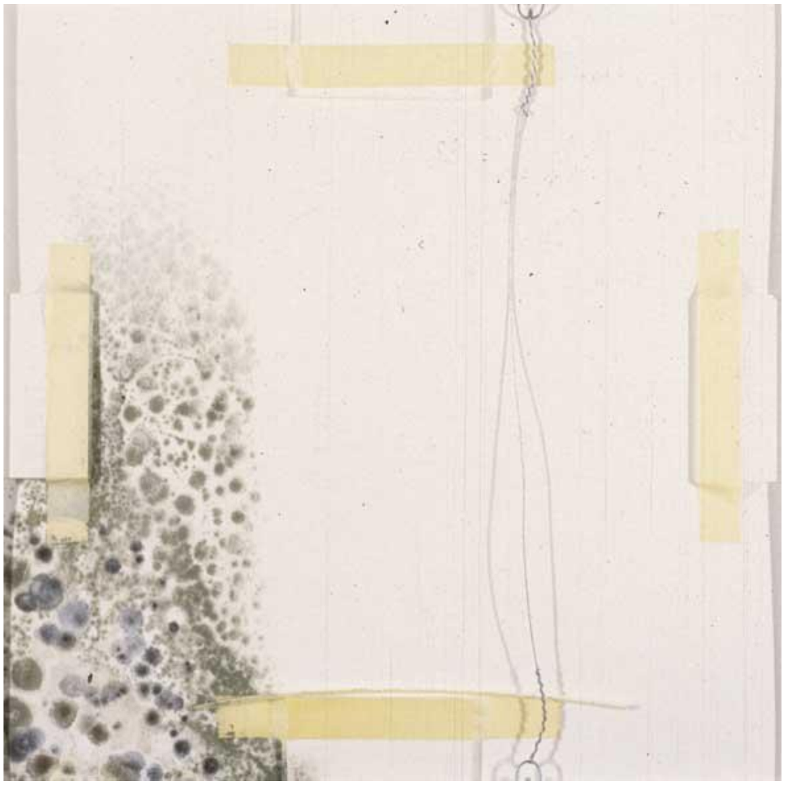

Figure 2. Mould colonies on the back of a framed print. Their distribution shows the effect of a microclimate created by the varying distance the backing board hung away from a damp wall. Where the gap was wider (top of picture), ventilation could occur by convection; this prevented moisture from building up to levels that allow mould growth. Where the gap was narrow (bottom of picture), the convection of ventilation was restrained; this allowed enough moisture to support mould growth to diffuse to the backing board.

For bacteria to survive, water is needed in the form of continuous very high relative humidity (RH) and a high moisture content in the substrate, which includes environments that are under water. Except for spore-forming bacteria (a survival mechanism that greatly enhances the pathogenic nature of tetanus, botulism, anthrax, etc.), most bacterial risk is severely restricted by avoiding constant high humidity or saturation. Many bacteria species are controlled if conditions are drier than 90% RH. All growth is stopped by an RH level below 70%. For microorganisms, RH is usually expressed in terms of water activity. Other factors in the bacteria's environment that can affect the colony's success are temperature, nutritional value, and pH of the substrate. Specific bacterial risks are associated with contamination by soil, dead or infected animals, stagnant water, nutrient-rich fluids, and sewage. These associations can cause such hazards as anthrax, "Legionnaires" disease, botulism, and so forth. However, a return to environmental conditions unfavourable to bacterial growth does not ensure that pathogenic bacteria or their toxins are destroyed; therefore, anyone working with suspect materials must protect themselves properly.

Moulds are less constrained by a lack of water than are bacteria. However, mould growth is limited by the water available in the substrate material. Many mould spores need near-saturation conditions to trigger germination, and continued moisture to survive. Once the hyphae develop, even the most hardy mould species require moisture levels of at least 65% RH to continue to grow. The vegetative hyphae (in the form of fibrous mats and filaments called mycelia) search for nutrients and digest the substrate. Certain wood-destroying fungi can carry water through long hyphal strands, which means growth can be supported far from the sustaining dampness. Fungal spores are produced above the vegetative growth (the mycelial mat) in specialized organs. These spores are easily spread by air currents and through contact with humans and other organisms.

If moisture is supplied by damp air, mould can be marginally viable in nutrient-rich materials stored above 65% RH. Mould growth increases in vigour above 75% RH, and becomes strongly active above 85% RH. Mould growth is ultimately restrained by immersion in water, which limits oxygen availability. Mould growth is also limited by dehumidification, which consequently limits the amount of water that is available for use in the substrate. This limiting condition is reported in food science literature as "water activity" — a numerical value equal to RH expressed as a fraction (e.g. 75% RH = 0.75 A_w). In situations where moisture comes from a reservoir of dampness (e.g. soil), the moisture content of the material in contact with this reservoir (e.g. wood sills) has to be reduced to prevent rot. When using moisture meters to determine if organic material is capable of supporting mould growth, the RH limits for growth (say 65%) need to be converted into an equivalent moisture content using a sorption isotherm for that material.

Microorganisms digest, stain, weaken, convey moisture (e.g. "dry rot" fungi), and attract insect pests by modifying and augmenting the nutritive value of an object. Aside from the pathogenic effects of infection, bacteria and fungi pose a health risk to humans simply through high concentrations or chronic exposures that lead to allergic and severe respiratory conditions. Using effective personal protective equipment is strongly advised when working with microorganism contamination (Strang and Dawson 1991a; consult Guild and MacDonald 2004 for current recommendations on working with mouldy collections).

Insects

Insects and other arthropods are the most numerous animal pests. Because of their specialization, small size, mobility, sensory capability, and fecundity, insect pests are a persistent threat to the collections they favour (Figure 3).

Figure 3. Anobid beetle larvae have chewed most of the wood away from this table's leaf support. Very little activity is seen, however, on the exposed varnished surfaces.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Insects can have very specialized food requirements; therefore, the hazard they pose should be thought of in terms of material type, not object type. Insects are normally present in the natural environment and find their way into collections. Or, they enter collections from infested objects that are sent on loan or are newly acquired, much as insect pests are carried around the world through trade and travel.

Insect life cycles vary. The two common patterns are:

- egg → larval stages → pupae → adult
- egg → nymph stages → adult

Larvae and nymph stages are marked by more or less constant eating and growth. This encourages multiple moults as the insect outgrows its hard integument (outer shell). Adult forms may not eat (e.g. clothes moths), may eat different foods than they do in their larval stage (e.g. dermestids), or be as voracious as larvae are on the object (e.g. **Stegobium**)[2]. Pupation may occur away from the food substrate, which decreases the chance the pupa will be preyed upon. Adults may also seek alternative sites to meet mates (e.g. dermestid adults meet on flowers where they also eat the pollen). Insects often rely on pheromone cues to find mates (e.g. clothes moths and wood-boring beetles). Some insects disperse quickly throughout collections, while others tend to stay in one place and reinfest the same materials over subsequent generations. However, the potential to spread is always present.

Insects, and less commonly other arthropods, in their need for food and shelter cause damage ranging from incidental soiling to complete digestion of organic materials. Some insects will also bore into soft plastic foams and materials composed of minerals to lay their eggs or to pupate. Some insects transmit human diseases. The presence of food pathogens, insect body parts, and faecal matter in collections can induce allergic reactions in humans. Therefore, precautions similar to those for handling mouldy material should be used when working around insect-contaminated objects.

Rodents

Rodents are the most dominant mammalian pest in agriculture and commerce. They are usually present in urban or rural localities. (Alberta is the major exception: its long-running, province-wide rat extermination program has been very successful.) Rats and mice easily climb, burrow, swim, and gnaw. They are also very fecund. Because they are often associated with human food and garbage, they are frequently found in collection buildings. They usually establish home ranges within a 20- to 60-metre radius, but may range even farther.

Mice usually establish territories within a 20-metre radius, or even smaller areas inside a building, but can range farther abroad, even up to a couple of kilometres. They breed quickly and, thus, will spread out looking for more resources (food, water, and nesting material). They may find these resources easily available in collection rooms. Rats also live in colonies. They live in established burrows outside buildings or in nests inside a building. Because all rodent pest activity is strongly associated with food availability, control activities are often aimed at making these resources unavailable.

[2] Termites and some wood beetle pests harbour symbiotic microorganisms that help them digest otherwise inedible matter.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Rodents gnaw all the time on non-food items to deliberately wear and sharpen their constantly growing teeth. They cache food for future use; urinate to form trail marks and deposit faeces as they explore; leave grease marks along trails; disrupt material by gathering nest materials; and create shelters in protected locations (Figure 4).

Figure 4. Rats have left distinctive grease marks on the walls where they constantly rub as they move around their range. Photo: Department of Integrated Pest Management, University of Aarhus.

Dead rodents, sloughed hair, and faecal matter attract and support keratin- and protein-eating insects, which then can spread into collections. A number of human diseases are transmitted from rodent waste; therefore, using respiratory protection and barrier-protective clothing is advised when cleaning any rodent-infested material.

Birds and bats

Several species of birds roost or build nests on buildings. Their nests and faeces soil and deface the supporting structure. This detritus supports populations of keratin- and protein-eating insects. Their nests also harbour parasites. Exposure to avian source dusts (created from faeces, feathers, and nesting materials) may enhance the development of bacterial and viral zoonoses (e.g. chlamydiosis in pigeons and poultry) as well as cause chronic allergic responses. These reasons, along with disturbing patrons by defecating in public spaces, are incentives for suppressing birds (most often pigeon flocks). Accumulations of bird guano (e.g. in attic roosts) can pose microbial human health hazards if this dust is inhaled (e.g. histoplasmosis, cryptococcosis); therefore, full respiratory protection, barrier-protective clothing, and post-exit sanitary practices are advised if entering these spaces or removing such wastes (Strang 1991b). Several prevention methods can be used to reduce bird roosting in vulnerable locations (Figure 5).

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Figure 5. Anti-bird roosting spikes on this heritage building protect patrons and the structure from soiling.

Bats roost in attic spaces and wall cavities that are open to the outside. They can enter through gaps larger than 5 mm. Their accumulating faeces can raise similar hazards to those of birds. Staff are advised to handle these wastes in an equivalently safe manner. (For a basic guide for bird and bat exclusion, consult Strang 1991b; for a guide for personal safety, consult Guild and MacDonald 2004.)

Sensitivities of collections to pest attack

What pests want

The object stands in for what the pest would normally search for (food, water, or nesting materials) in its natural environment.

Surface effects from infestations range from cobwebs and dried faecal excretions, to urine stains and agglomerations such as bird nests, and mud wasp and paper wasp nests. These surface effects can permanently mar an object's vulnerable finishes or accelerate a microbial attack on an object.

Grazing and gnawing activities are accelerated by surface deposits and salts that attract a pest, or by the pest's need to chew. Pests chew and digest these materials, not the objects per se. Their attraction to particular objects may be further increased by the object's design if it facilitates access (e.g. the rough surface of an exposed end grain that allows the wood borer to lay its eggs) and shelter, or by residues on the surface. Whatever the reason, it is the pest's native ability to recognize and utilize the material that stimulates and sustains pest damage.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

In describing the risks, listing some representative object classes will indicate the vulnerability of materials and the possible extent of pest risk. (Consult Materials, objects, and common damaging insect pests, which uses familiar curatorial categories of materials.)

Materials, objects and common damaging insect pests

Material	Damage to representative objects	Common pests
Cellulosics: Solid masses such as timbers and shelved books	Holes bored in book block and board book covers, wood implements, and furniture. Wood structures bored into are weakened, especially near end grain (joints) of beams, poles, piles, sills, rafters, and flooring.	Structural wood pests, lyctids (hardwood only), anobiids, longhorn beetles, carpenter ants, termites (limited range in southern Ontario and British Columbia). Also, a wide variety of wood-boring insects are found in rotten wood and wood outdoors in damp conditions.
Cellulosics: Paper surfaces	Grazing to eating book covers, artwork, letters, wallpaper, and insulation.	Silverfish, cockroaches, book lice (psocids).
Plant fibres and flower parts, leaves, and bark	Herbarium specimens, baskets, cordage, and coarse-fibre goods.	Cigarette beetle (**Lasioderma serricorne**), drugstore beetle (**Stegobium paniceum**), **Reesa vespulae**, ptinids.
Starches	Boring into stored seeds and grains. Consumption of adhesive paste joints.	Weevils, Indian meal moth, cockroaches, silverfish.
Keratin: Hair, fur, nails, horn, and baleen	Stripping of fur clothing, hair embroidery, quillwork, and natural history specimens.	Clothes moths and dermestids.
Collagen: Skin, hide, and parchment	Garments, sinew cordage, bags, drumskins, glue joints, and book bindings.	Many dermestids, commonly **Anthrenus** and **Attagenus** species, **Thylodrias contractus**, and ptinids (spider beetles).
Mouldy and damp objects	Grazing on micro-moulds found on archival paper, artworks.	Psocids (book lice) and lathrids (plaster beetles).

CCI Technical Bulletin Nº 29.

Sensitivities to moulds

All organic and inorganic surfaces can be colonized by moulds under the right conditions of high humidity and dispersion of nutrients. Damp cellulosics (paper) and proteinaceous (parchment) materials are the most affected because they are entirely digestible, relatively soft, and can be hard to clean at the porous cellular level where microorganisms contaminate an object (e.g. invasive fungal hyphae, tiny spores with strong pigmentation). Paper and parchment objects often have high information content (text, illustrations, etc.), so the obscuring effects of microorganisms are often gravely disfiguring. Moulds will

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

also grow on inorganic surfaces in the presence of nutrients and moisture. The ability to identify microorganisms and their degree of risk to people and materials requires special equipment and training. Being able to distinguish surface mould from dust and other soiling matter is a useful skill that will help guide preventive conservation decisions.

Sensitivities to insects

Due to insects' specialization in feeding, burrowing, and breeding activities, there is a wide diversity in a collection's vulnerability to specific insects. However, some insect pests are generalists, and will affect related groups of materials.

Insects are specialized in their feeding habits due to differently adapted mouthparts, digestive systems, and symbionts (e.g. gut-dwelling microorganisms that convert cellulose to usable sugars). For example, different insects are attracted to dry seeds and to starch-adhesive pasted paper. Although both objects are largely starch-based, weevils are more likely to attack dry seeds and silverfish are more likely to attack starch-adhesive pasted paper because of their different mouthpart structures.

Soiling of objects increases their susceptibility to pest attack, in particular silk and cotton fabrics. These fabrics are not usually eaten as food by insects without the presence of added nutritional materials.

Consult Materials, objects, and common damaging insect pests for a material's vulnerabilities and the corresponding insect pest that will attack the material. Major insect pests and their associated, diagnostic signs describes the insect pests referred to in Materials, objects, and common damaging insect pests.

Anobium punctatum (furniture beetle), adult.

Stegobium paniceum (drugstore beetle), adult.

Anthrenus scrophularia (common carpet beetle), adult.

Anthrenus scrophularia, larval cast.

Attagenus spp., larval cast.

Tineola bisselliella (webbing clothes moth), stages and frass.

Tinea pellionella (casemaking clothes moth), stages.

Lepisma saccharina (silverfish).

Blatella germanica (German cockroach).

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Camponotus spp. (carpenter ant), and galleries.

Liposcelis spp.
(psocid or book louse).

Mouse trapped while damaging attic insulation.

A mud wasp nest disfigures this sculpture.

Dermestid larvae eat trapped insect bodies and move on.

Webbing clothes moth damage to textile.

Clothes moth larvae ate this porcupine quillwork.

This anobiid adult failed to break free of the painted sculpture.

Silverfish grazed on and perforated this envelope.

Major insect pests and their associated, diagnostic signs

Common name	**Latin name**	**Presence indicators and characteristics**
Powderpost beetles	Lyctus brunneus and others	Small round holes in wood and floury frass. Lyctids are small brownish adults, attack only hardwoods. Prevalent across Canada and a common problem.
Furniture beetle Cigarette beetle Drugstore beetle	Anobium punctatum, Lasioderma serricorne, Stegobium paniceum	Small round holes in wood and granular frass. Anobiids are most common in wood objects of European origin, but native species (**Hemicoelus** spp.) can attack structures. **S. paniceum** and **L. serricorne** are severe pests of organics in collections.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Longhorn beetles Old house borer	Hylotrupes bajulus	Large oval holes and cavities in timbers. Cerambycid spp. are a timber pest in Canada. Most will not reinfest seasoned wood. While introduced species are now damaging hardwood and softwood trees, only **Hylotrupes bajulus**(old house borer) has the potential to be a severe pest in museum collections due to its capacity to reinfest old timber. It is predominantly limited to the eastern United States.
Wharf borer	Nacerdes melanura	Wharf borers have been found in Canadian heritage sites associated with damp timber or wood mill waste.
Flathead borer	Buprestis aurulenta	Large oval holes in timber. Metallic-coloured buprestid borers have emerged from timbers in historic sites and collections, sometimes many years after cutting the timber. They are not likely to reinfest.
Hide beetles Carpet beetles	Anthrenus verbasci, Thylodrias contractus, Attagenus unicolor, Dermestes maculatus, Anthrenus scrophularia	Brown-banded “furry” larvae and cast skins found on furs, feathers, or roaming on objects, frass piles, and loose hairs in drawer bottoms. Among the most common of collection pests. Dermestids are natural scavengers of nests and dead animals. Adults associated with wildflowers. Natural history museums use colonies of **Dermestes maculatus** to clean specimens.
Webbing clothes moth Casemaking clothes moth	Tineola bisselliella, Tinea pellionella	Small, white larvae in webbing or flattened cocoons on surfaces, grazed “channels” on or holes through wool fabric. Common in historic collections and very destructive. Tineid adults are small, whitish moths with fringed wings. Sometimes confused with Indian meal moth infestations. (Cracked seeds, grains) but **Plodia interpunctella** has coppery “shoulders”.
Silverfish	Lepisma saccharina	Grazed surfaces or ragged holes in paper. Silvery fish-shaped nymphs and adults, **Lepisma** have two sweeping antennae and three trailing hairs.
German cockroach	Blatella germanica	Nymphs and adults are brown with two dark stripes on thorax. **Blattella** are very fecund. They aggregate on spilled foods; starches preferred. Can affect objects made with starch pastes.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Book louse	Liposcelis species	Tiny, translucent, bulbous abdomens, commonly wingless. Psocids favour dampness, but can roam for a couple of weeks in drier locations. Commonly grazing microbial contaminants on paper, and a warning of damp conditions.
Carpenter ant	Camponotus pennsylvanicus, Camponotus herculeanus, Camponotus modoc	Large black ants, commonly seen roaming in springtime. **Camponotus** will hollow out rotted trees or timber, ejecting frass that looks like saw shavings. Can be severe pest of timber in historic buildings, fencing, and susceptible trees on grounds.
Termites	Reticulitermes flavipes, Reticulitermes hesperus	Subterranean; larvae may build shelter tubes. Adult **Reticulitermes** can be seen flying (as ants do). Unlike ants, termites have a thicker "waist". They are a regional hazard in Canada (southern Ontario, southern British Columbia, southern Manitoba). While not yet destructive to heritage in Canada, a potential hazard where present.

CCI Technical Bulletin Nº 29.

Sensitivities to rodents

Rodents will damage any material that can be chewed or gathered for nesting, including glass fibre insulation. They can carry noxious material in their mouths without risk of swallowing the material. Any materials that are stored in the path of rodents searching for food will be soiled by urine traces and faecal pellets. Any collection object made of starch, protein, or fat (favourite rodent foods) will be consumed or damaged and soiled or removed to another location. Besides creating larders, rodents will also use some areas as common defecation areas — a behaviour that intensifies damage if it happens to be on or within an object. Major rodent pests lists major rodent pests.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Major rodent pests

Common name	Latin name	Description
Brown or Norway rat	Rattus norvegicus	Omnivorous, 30–45 cm long, brown with light grey belly, blunt nose, short thick ears.
Black or roof rat	Rattus rattus	Omnivorous, approximately 42 cm long, black or brown-grey with lighter belly, pointed nose, thin large ears.
House mouse	Mus musculus	Omnivorous, preferring grains, approximately 17.5 cm long, brownish grey with grey belly, pointed nose, large ears.
Deer mouse	Peromyscus maniculatus	Prefers seeds and insects, 15–20 cm long, brown with white belly and white on the underside of tail, large protuberant eyes, large round ears. May overwinter in buildings. Main concern is its link to the hantavirus, a health hazard, transmitted through faecal material and saliva.

CCI Technical Bulletin Nº 29.

Sensitivities to birds and bats

This group of pests is more harmful to heritage structures and less harmful to collection objects. Unrestrained nesting activity introduces soiling, insect pests, dead bodies, and smells that are at least annoying and, at most, health hazards.

Only 3 of the 19 Canadian bat species habitually roost in buildings: little brown bat; big brown bat; and Yuma bat (Strang and Dawson 1991b). Likewise, only a few bird species will cause significant problems: rock dove; house sparrow; starling; and some swallow species (Strang and Dawson 1991b).

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Control activities

The impact of pests can be controlled. It takes basic, but prompt, attention to maintenance and effective sanitation practices to prevent pest access and their spread in collection spaces. Systematic detection programs catch problems early and influence appropriately scaled responses to limit pest damage and remove the offending organism.

Specific action to prevent pest damage can often be used against many pest types. Common situations and preventive actions in the following tables are coded to the specific pest subtype using the following symbols:

- Microorganism
- Insect
- Rodent
- Bird and bat

Avoid

Avoid, remove, or mitigate the effect of pest attractors to deny them necessary life support. While collection objects are often made of materials inherently attractive to pests, the integrated pest management (IPM) goal is to ensure that the object's storage and display surroundings do not support pests (Figure 6).

Actions to avoid pest problems

Pest	**Situation to avoid**	**Action**
Microorganism symbol Insect symbol Rodent symbol Bird and bat symbol	Spilled or open food (starch, protein, fat) attracts and supports all pest life.	Restrict food areas to places segregated from collections. Encourage the use of tightly sealed food storage containers. Promptly clean up all spills and event areas where food has been served. Flag any foodstuffs (e.g. stuffed animals) in interpretive displays for regular IPM inspections. Consult Case Study 1.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Microorganism symbol Insect symbol Rodent symbol Bird and bat symbol	Sources of moisture support fungi, bacteria, rodents, and some insects. Standing water is a minor attraction for bird pest species.	Reduce standing water where possible. Include water features in a detection regime to identify developing hazards (mould around courtyard fountains, etc.). Inspect sumps and drains in collection storerooms to see if they are supporting silverfish and nuisance pests. Ensure water drains away from all structures to prevent foundation moisture problems.
Microorganism symbol Insect symbol Rodent symbol	Food, sweat, and blood residues on objects attract pests.	Grazing by insects and gnawing by rodents is increased by residual foodstuff on textiles, baskets, containers, etc. Cleaning these objects will lower their attractiveness to pests and microbial attack in damp conditions. If a residue must be preserved, use blocking strategies to deter pests.
Insect symbol Rodent symbol Bird and bat symbol	Deliberately feeding animals attracts pest problems.	Unnecessary feeding (e.g. urban pigeons) encourages roosting, soiling, and nesting, and attracts insect pests that feed on bird detritus (e.g. clothes moths, dermestids) to collections. Permanent roosting or nesting activity in or on a structure is high risk for introducing harmful insects. Where feeding programs are part of the interpretation plan, reduce risk by ensuring IPM principles are applied in the area and by properly storing foodstuffs.
Microorganism symbol Insect symbol	Elevated moisture content supports bacteria, mould, and some insect life (silverfish, psocids).	Dehumidify storage to less than a seasonal high of 75% RH for periods lasting less than 2 months, and preferably under 65% RH for year-round storage, which will reduce object moisture content to safe levels, or package vulnerable objects in sealed vapour-barrier containers during the dry season and leave them sealed throughout the damp season (Strang 1998).

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Microorganism symbol Insect symbol Rodent symbol	Clutter implies uninspected areas that possibly harbour rodents and insects. Combined with damp, permanent clutter exacerbates mould problems by providing more surfaces to contaminate in vulnerable places.	Reduce clutter by organizing objects on shelves or clean pallets. Keep clear lines of sight along walls because rodents use room edges as runways. This is also useful for water damage mitigation, intruder detection, and emergency exit.
Microorganism symbol Insect symbol	High humidity conditions (greater than 65% RH).	Microorganisms and some insects require high humidity to go through their life cycle. Reducing humidity year-round to less than 65% RH avoids conditions conducive to bacteria, mould, and some insect proliferation (i.e. psocids). Likewise, maintaining alcohol preservation at 70% (volume percent) ethanol/water and 40% isopropanol/water avoids microbial action deterioration in fluid collections.
Insect symbol	Light draws night-flying insects toward and into structures.	Arrange exterior lights to minimize this effect without compromising security. Use light to draw insects away from building openings. Mercury vapour lighting is very attractive to insects. Energy-efficient, high-pressure sodium exterior lighting is less attractive to pests. Reduce use of nighttime interior lighting that is visible to the outside.
Insect symbol	Wildflowers are feeding and mating sites for adult dermestids.	Be cautious about bringing in fresh cut wildflowers without removing insect life, or ban the practice. In comparison, cut flowers from reputable florists and cared-for houseplants are a much lower hazard, but must be removed at the first sign of plant pests.
Insect symbol	Concentrations of pollen or hair in dust may support insect life.	Overall cleanliness decreases available food for pests, and increases the effectiveness of detection efforts and applied pesticide sprays. Vacuum annually under cabinets. Certain mineral dusts designated as pesticides decrease viability of insects (diatomaceous or synthetic silica powder formulations).

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Bird and bat symbol	External parts of building structure amenable to nesting and roosting.	Discourage nesting or roosting on a building by using blocking methods such as netting. Providing alternate habitats (bird or bat houses) away from a structure may reduce pressure for finding nesting and roosting spots and aid species at risk.
Insect symbol	Wood-boring pests introduced into key structures (building, storage furniture, display, crating).	Use "manufactured" wood products (plywood, laminated beams), and avoid solid wood elements unless they have been kiln dried, which will kill borers (International Standards for Phytosanitary Measures, ISPM 15). Avoid re-using framing timbers unless kilned or treated.

CCI Technical Bulletin Nº 29.

Figure 6. In this small, cluttered, poorly organized museum storeroom, it is difficult to do any IPM or other tasks.

Block

Segregate valued objects from pests by using pest-resistant materials and practices that will delay or deny access. Use the building as the primary protective barrier. Try to achieve subsequent layers of protection through architectural design that incorporates barriers to pest access, eases inspection and remediation (consult Imholte 1999), and provides for tightly constructed specimen cabinets. Effectively blocking pest

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

entry requires attention to all seals and junctions on a structure, and ongoing timely attention to maintenance (Figure 7).

Actions to block pest activities

Pest	Situations requiring blocking	Action
Microorganism symbol Insect symbol Rodent symbol	Health hazards from handling mould, faecal contamination, dead rodent bodies.	Prevent exposure to health problems. Animal faeces and carcasses can present viral and bacterial hazards. Dusts of insect origin are strong causes of allergic reactions (Strang and Dawson 1991a, 1991b). Therefore, wear approved respiratory protection, gloves, and protective or disposable coveralls when dealing with mouldy buildings and objects or insect- or rodent-infested collections.
Insect symbol Rodent symbol	Building vulnerabilities that allow ingress of certain pests.	Repair foundation cracks over 1mm wide (0.3 mm in termite zones). Seal gaps between continuous sheet flooring and walls. Apply blade seals around opening windows and under doors. Attach wire mesh to exterior vents to restrict animal access (6-mm hardware cloth to restrict mice, 1-mm mesh to restrict most insect pests).
Microorganism symbol Insect symbol Rodent symbol	Improperly sealed metal or wood cabinets that allow pests to enter.	Use pest-resistant materials (e.g. tough silicone rubbers) to maintain effective door seals. Ensure fixtures do not compromise the barrier due to unsealed perforations (e.g. levelling feet, recessed handles, or vents). Ensure objects are pest-free before enclosing.
Microorganism symbol Insect symbol	Archival banker boxes are open to pests due to the handle space and loose-fitting lids. Boxes require taping for complete closure. Objects inside should be sealed in a polyethylene liner for added security in hazardous situations. Cardboard box walls can be penetrated by pests (rodents, some insects),	

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

	but will protect contents from rodent urine and faeces. Ensure objects are pest-free before enclosing.	
Microorganism symbol Insect symbol	Oversized and oddly shaped objects, which need protection.	Use pest-resistant films (rolls of sheet material or pre-made plastic bags): polyethylene is a good barrier material that protects up to 10 years; poly(ethylene terephthalate) such as Melinex or Mylar is a better barrier for multi-decade protection. Bags will protect objects from incidental rodent urine and faeces dropped as they explore, but not against their chewing. Heat seal bags for complete closure, or use a tight, multiple-folded mechanical seal. Tightly gathered closures are insect resistant in the short term. Insect perforation of plastic film depends on the ability of the insect to perforate the plastic as well as on the inherent strength of the plastic. Folds in the plastic will greatly increase the bag's vulnerability to insect perforation because a fold presents places where an insect can grab on more easily and chew. Ensure objects are pest-free before enclosing. Do not place a bagged object where it will be subject to a temperature differential. This creates damp areas and risks mould formation (Strang 2001).
Bird and bat symbol Rodent symbol	Structural features that offer shelter and can be used as roosting and nesting sites.	Cover bird roosting sites with black nylon bird mesh. Block unused chimneys at roof level with sheet metal caps, or install screening on functional chimneys to prevent bird access. Use bird spikes to deter roosting on beams and other structural features.
Microorganism symbol Insect symbol Rodent symbol	Vials containing small objects.	Screw-top glass vials are resistant to insects as long as the inner seal conforms tightly to the rim. Earliest stage clothes moth larvae can penetrate gaps as small as 0.1 mm. Tight-fitting lids designed for holding fluids are generally secure.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

 Microorganism symbol  Insect symbol  Rodent symbol	Quarantine.	Any effective barrier, from a sealed room to bags, can be used as a bulk quarantine area until an object can be treated to kill pests. Control use of this space so that quarantine is not broken. Combine with timely control methods to protect all uninfested collections. New acquisitions and incoming objects on loan can be hazards in a pest-free storage area.

CCI Technical Bulletin Nº 29.

Figure 7. Effective weather stripping on an exterior door greatly reduces the ability of pests to enter the structure, despite high insect and spider activity under nighttime lighting. Better cleaning is needed, as seen by the residues near the door.

Detect

The philosophy behind pest detection is "early warning — easier cure". Accommodate detection methods in storage areas and exhibit designs by incorporating a means of access for the staff and discouraging creation of blind cavities. This is also important for supporting sanitation practices. Both traps and direct inspection can be used effectively to find pest problems (Figure 8). Encourage as many staff members as possible to regularly check for pests by providing basic IPM information sessions and by creating an easy-to-use pest incident report system. Detect pest lists actions that help detect pests.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Detect pests

Pest	**Detection methods**	**Action**
 Microorganism symbol  Insect symbol  Rodent symbol  Bird and bat symbol	Identification	Know your pests! Knowledge guides an appropriate and effective response. To save time and avoid frustration, limit identification information to what is needed (clear recognition of hazard). Learn to discriminate mould from dust, dirt, and stains. Learn to identify your insect pests (Major insect pests and their associated, diagnostic signs). Maintain a general collection of identified specimens for comparison and training. Acquire guide books and identification keys to help staff identify pests. Learn to identify rodent droppings and how to find rodent urine trails using UV light. Learn to identify grease marks made by rodents and bats that identify common pathways and entrances. A simple but powerful hand lens is an invaluable identification tool. Section 7 lists the necessary equipment for a basic identification kit.
 Microorganism symbol  Insect symbol  Rodent symbol  Bird and bat symbol	Visual inspection provides detailed knowledge.	Because storage and display containers often hide objects from view, detection of pests is related to the ability to enter a space or open a container. Visual inspection programs ensure that low-use collections remain pest-free. Using white acid-free paper to line drawer bottoms or to line storage shelves greatly enhances the visibility of small insect bodies, clipped hair, and frass. An annual visual inspection coupled with effective responses will reduce or eliminate endemic pest problems. A bright flashlight is an invaluable inspection tool to locate signs of infestation such as frass and webbing. Check windowsills and light fixtures for adult beetles. Prioritize inspection if you are dealing with large numbers of objects. Start with those that contain materials most vulnerable to pests, have high value, and are housed in structures that provide poor protection.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Insect symbol Rodent symbol	Trapping provides information when people cannot see the pest.	Deploy adhesive traps for insects. For rodents, use adhesive, snap (break-back), or cage traps (single or repeating) to discover the presence, the type, possible distribution, and frequency of a pest. Traps are especially useful for confirming rodent presence in large structures. Key locations are near exterior doorways, food preparation and waste areas, sumps for water, mechanical rooms, pipe chases, and along walls in collection storage areas.
Insect symbol	Use pheromone lures, food lures, semiochemicals.	Trapping with lures is a way to increase the efficiency of using traps that a pest might only blunder upon. Only a few commercial pheromone lures are available for museum pests, but they are generally effective at drawing in male insects. Food lures and other semiochemicals enhance trap efficiency for insect species that are feeding and mobile (e.g. dermestids, cockroaches). Because pheromones are specific to certain species, there are limits to using lure technology, so ensure the correct lure is used in the recommended manner for the appropriate pest.
Microorganism symbol Insect symbol Rodent symbol	Records give you greater knowledge of vulnerabilities and costs, and assure corporate memory of IPM issues and treatment.	Establish effective pest logs (consult Section 8). Chart progress using simple lists and totals over time. Use maps when an illustration will convince others of recurrent issues and will help better organize the information needed for remediation actions.

CCI Technical Bulletin Nº 29.

Key locations to monitor are:

- collection storage areas
- in and under display cabinets
- food service areas
- mechanical and service rooms
- basements
- all entranceways
- fireplaces

Other locations should be added when a significant pest presence is noticed. Consult Strang (1996a, 1996b) and Pinniger (2004) for information on detection programs. Consult the Bibliography for pest identification guides, which will help establish in-house expertise.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Figure 8. This adhesive insect trap is designed to fit into the floor–wall junction and intercept moving pests. Periodic inspection and replacement of traps indicate what insect pests are currently in your building and which ones may be affecting your collection.

To assist in pest detection, assemble the tools listed in Equipment for detecting pests in a convenient carryall.

Equipment for detecting pests

Detection equipment	**Purpose and use**
Magnifying loupe	Discerns characteristics of small insects and helps distinguish between moulds and dirt. 7–20 × magnification is useful.
Powerful flashlight	Illuminates dark areas, objects under loupe. Use raking light to create shadows that will help reveal insect bodies and rodent droppings.
Tweezers, spatula	Use to pick up samples without damaging them or exposing yourself to hazards.
Small clear containers, bags	Use to store and annotate samples of insects or other signs of infestation for reference, or later to confirm identity.
Permanent fine marker	Use to label containers with location, date, object contained, and other useful data.
Ultraviolet lamp and UV protective goggles	Use small battery-powered UV light unit to reveal rodent urine trails. Use protective goggles and do not unduly expose skin to UV.
Rodent traps	Place in key locations; check frequently fora ctivity. Reset trap after a rodent is captured.
Insect traps	Place in key locations, check frequently for activity. Replace regularly after insects are first found on trap (prevents dead insects being used as a food source for dermestid larvae) or when fouled.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Identification guides	Consult the Bibliography for suggested texts, acquire locally useful guides and identification keys, and make your own general collection of identified pest and non-pest species.

CCI Technical Bulletin Nº 29.

Record keeping to assist IPM activities lists the minimal information needed to create effective trapping and visual inspection records. The purpose for keeping good permanent records of pest activity is to discover and track recurrent problems, or to demonstrate that pest-related problems have been solved by remedial actions. Trap and visual inspections can be recorded in separate ways as long as the information can be coordinated for reporting the results. Paper records can suffice, but electronic versions facilitate working with the data and analysing results with computerized plotting and presentation software.

Record keeping to assist IPM activities

Record field	**Purpose**
Location	Trap locations must be located on a floor plan. Trap locations may be permanent or temporary. Pests are often associated with specific habitats in buildings. Location data help define hot-spots and sources, or show if there are low levels of pests distributed throughout the space. Relate visual inspection locations to cabinet numbers, collection elements, room numbers, windowsills, lighting runs, etc.
Trap type	Type of trap, brand, design, baits, etc. can all have a bearing on their effectiveness against different organisms. Recording this information can show trends and guide future trap choices and use.
Trap ID	Each trap can be given a marked "serial number" to permanently distinguish it from others in a database. Trap ID is necessary if traps are collected in a sweep, bagged, frozen (to kill insects), and examined later at a convenient time and location.
Date trap laid and removed	The period of trapping is a sample in time. This information is essential for presenting a time series showing annual fluctuations or trends.
Affected objects	Discovered by visual inspection. Identification of affected objects will guide the delivery of remedial treatment to affected objects.
Treatment	Record treatment type, protocol, cost in time and money, and dates. Ensures the problem has been addressed and satisfies conservation ethics. Allows check on effectiveness.
Pests	List the pest and non-pest organisms found, and their stage of development (e.g. larvae, adult). Use a level of identification that reveals the risks each pest presents to the collection. This list is useful when proposing effective remedial actions.
Count	List the numbers of each pest found, dead or alive. Over time, this information gives a picture of the intensity of a current infestation and the "normal" level of pest activity, once control measures are in place.
Comment	Note if the trap has been tampered with, odd occurrences, etc.
Observer	Useful in larger organizations to know who did the documentation.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

CCI Technical Bulletin Nº 29.

Respond

Eliminate pests from structures, objects, and support materials by methodical planning and use of appropriate measures (Figure 9). The priorities are to use methods that are effective, environmentally responsible, and inexpensive. Response methods to eliminate pests lists responses by target pest subtype.

Response methods to eliminate pests

Pest	Response methods	Action
Microorganism symbol Insect symbol Rodent symbol	Sanitation to reduce pest populations.	Aggressive application of **Avoid** and **Block** stages. Physical removal of pests and frass, by picking or brushing by hand, or by vacuuming. Sweeping and mopping are less effective than vacuuming to remove most pests.
Microorganism symbol Insect symbol Rodent symbol Bird and bat symbol	Subdivide for protection, quarantine, and treatment.	Seal objects in containers or bags to subdivide problems into manageable units for treatment.
Microorganism symbol	Dehumidify to remove hazard.	Mould growth occurs only in conditions above 65% RH (or equivalent moisture contents for each material). Changing ventilation patterns or adding effective refrigerant or absorbent dehumidification systems to reduce high humidity throughout the year will reduce mould damage. For example, consult Case Study 2.
Insect symbol	Dehumidify to reduce viability.	Damp-loving insects (e.g. silverfish, psocids, lathrids) require elevated humidity for at least part of their life cycle. Eliminating damp in walls, basements, attics, and service rooms year-round will reduce the numbers of these insects.
Microorganism symbol	Cutting off or restricting ground water.	Water that is taken up into organic structures accelerates fungal attack. Using dampproof layers, including materials to drain water away from site, and elevating structures to break absorbent contact with soil are three strategies that slow fungal attack.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Insect symbol	Cool to exterminate or control.	Place affected object in a polyethylene bag or equivalent vapour-barrier container and hold (most conservatively) at −30 to −20°C for 1-2 weeks. −20°C for 1 week kills most insect pests infesting museums (Strang 1992). Lower than −40°C for insect pest control is not necessary and begins to risk thermal stresses on temperature-vulnerable composite objects (e.g. mixed metal-wood veneer). Permanent storage in cold rooms, at less than 10°C, will minimize insect damage risk, but elevate moisture risk and catastrophic mould risk if moisture is not controlled by bagging, mechanical systems, or prompt intervention if the system fails. There are very few objects in general collections that cannot be exposed to this cooling method. Consult Case Study 3.
Insect symbol	Heat to exterminate.	Heat an object at 55°C for 1 to several hours. Exposure is calculated on maximum thickness of the object component or determined by direct measurement of the object. Consult Strang (1995, 2001) for detailed guidance on issues surrounding heat disinfestation. Enclose the object in a water-resistant bag to prevent desiccation. A wide variety of objects can be safely heat treated. Solar heat can also be harnessed for this purpose (Strang 1995, 2001). Consult the "Thermal control application guides" section. Commercial heating processes balance moisture in the treatment chamber so individual bagging is not required. Wood for export shipments such as pallets and crating is now heat treated to destroy timber pests and marked "HT" (Canadian Food Inspection Agency, ISPM 15). Consult Case Study 4.
Insect symbol	Fumigation to exterminate.	Fumigate objects using carbon dioxide or nitrogen in approved plastic bubbles or fumigation chambers. Nitrogen fumigation by oxygen scavengers can be done in small bags, e.g. using Ageless with heat-sealable, oxygen-barrier plastic films (Maekawa and Elert 2003). Toxic gas fumigants are not desirable because of their environmental and health effects and chemical interaction with objects. Few toxic gas fumigants are available in Canada to use with museum objects or structural fumigation.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Microorganism symbol	Apply fungicide to exterminate.	Wood attacked by fungi can be treated in situ with fungicides. Borates, one of the lowest toxicity systems, continue to penetrate after application, but are washed out by surface water. Other residual fungicides may be coloured, less penetrative, or have restricted use. Surface sterilants, such as dilute sodium hypochlorite bleach (0.5%) or 70% ethanol, can be used on hard surfaces in places that do not directly affect objects. Quaternary ammonium compounds in cleaning solutions can also kill microorganisms but may affect metals, so do not use them directly on objects. The effectiveness of biocidal cleaning solutions depends on contact time.
Insect symbol	Apply pesticide to exterminate.	Pyrethroids (e.g. permethrin), carbamates (e.g. bendiocarb), etc. are generally applied as sprays of liquid chemical mixed with a diluting agent, now commonly wateremulsion-based formulations, but some solvent-based sprays exist. Baseboard, crack and crevice, and cavity sprays are advised. However, direct or incidental spraying of objects is highly discouraged, as it can cause staining as well as mechanical and chemical damage. Pesticides have a range of action speeds, but are not equally effective against all insect pests or life stages because of their differing abilities to be picked up and absorbed or ingested. Pesticides are registered for specific pests and cannot be used outside their defined purpose (Dawson 1992).
Insect symbol	Apply desiccant powders to exterminate.	Silica and diatomaceous powders especially formulated for insect control can be blown into problem cavities and dusted under permanent exhibits to eliminate pest shelters. The particulate size is larger than those types of particulates that pose a severe chronic exposure hazard to human respiration; however, protective equipment is necessary when working with these powders. Some powders are co-formulated with "knock down" pesticides.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

 Rodent symbol	Trapping to reduce a rodent population.	Snap traps can be baited and attached to runways. They generally ensure that the rodent is killed quickly. Adhesive traps are efficient and do not suffer from trigger failure. There are some guidelines for humane use, particularly early removal of a rodent caught in a trap, and killing it if it is still alive to reduce its suffering. Repeat action trap cages can remove larger numbers of rodents in high-population densities than can single traps. Live traps will not ensure the rodent is removed permanently from the site because they may re-enter after being released in the open. Sealing the affected space is essential for effectively trapping rodents in order to remove them from a building or they will continue to enter from exterior sources.
 Rodent symbol	Rodent baits to exterminate.	Toxic baits (e.g. warfarin) are delivered in bait stations to reduce inadvertent poisoning of pets and people. Toxic baits are not advised for use in collections for two reasons. Poisoned rodents may die in building cavities or in collections and attract very destructive insect pests. Rodents can carry poison baits and other items (e.g. glass fibre insulation) with their mouths in a manner that protects them from swallowing the materials. Rodents caching bait outside the bait station creates a potential poisoning hazard to humans. Bait stations are more commonly used outdoors around the periphery of buildings. Caution: rodenticide baits are dyed with warning colours (blue, red, green) commonly seen in food, particularly children's candy. Many rodent bait formulations also support insect pest life, so remove any bait after its utility decreases.

CCI Technical Bulletin Nº 29.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Figure 9. Household chest freezers and walk-in freezers can be used to disinfest most collection holdings. Other systems can also be scaled from small to large, depending on the situation.
Photo: R. Kigawa.

Comparison of treatment methods compares treatment advantages and disadvantages to help staff choose the best method for their facilities situation.

Comparison of treatment methods - Treatment for insect pests

Heating

To 55–60°C: Exposure time depends primarily on thickness of the object. Consult IPM application guides. Enclose the object in a vapour-barrier bag or equivalent container to contain the pests and eliminate the risk of moisture content change during heating. Space-frames[3] may need dunnage (natural fibre sheeting) to increase moisture control, or supply moist, conditioned air during the treatment (commonly 15% RH over ambient levels). Heating methods include radiant space heating, forced air, and solar heat (Strang 2001).

Advantages

Near universal efficacy against all insects. Universally available technology. Short turnaround time. Wide scale of proven application–from single objects to entire buildings.

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[3] Objects whose construction creates a large ratio of open space to their components. When bagged, this results in a large air volume to be buffered.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Disadvantages

Logistics of enclosure to ensure the necessary vapour barrier exists that will restrict change in moisture content and reduce heat loss, especially when treating large structures. Forced air circulation through air ducts and numerous monitoring points are necessary when treating large structures.

Cooling

To −20°C for 2 weeks or −30°C for a week: Enclose the object in a vapour-barrier bag or equivalent container to contain pests, reduce moisture content change, and eliminate condensation risk on rewarming (Strang 1992, 1997). Ensure that air flows completely around the object in the freezer chamber to prevent relatively warm "thermal bridges" forming. (When objects touch the chamber wall, they become part of the chamber's insulation, which allows heat to conduct into the objects from the outside.) As much as possible, carefully minimize the thickness of stacked, folded, or rolled objects before treatment so the largest surface area is exposed to cold air (e.g. books, carpets). Monitor temperature in the thickest object if possible to ensure the most effective temperature was reached. Consult IPM application guides.

Advantages

Widely available technology; household freezers adequate. Winter cold in some locations is sufficient (−25°C or less) provided the object has had a month at human comfort temperatures (i.e. 22°C) before exposure to break insect dormancy. Effective against most museum insect pests that are not preconditioned by cool environments.

Disadvantages

Logistics of enclosing large objects; however, a truck-body refrigeration unit can often be rented to do this. Minimum time in cold temperatures depends much more heavily on species characteristics than does heat treatment, so reducing exposure time is not recommended unless the species and its response are known.

Controlled atmospheres (low O_2)

Expose objects for 1–3 weeks in atmospheres that contain very little oxygen (insects succumb most efficiently to anoxia at less than 0.1%, a common specification for control). Note that wood borers are the most tolerant to anoxia, requiring longer exposures. This fumigation technique uses compressed nitrogen (N_2) gas in larger enclosures or oxygen scavengers in smaller volume enclosures. Oxygen barrier films are heat sealable and may only be used once or a few times. Flush out air from anoxic bags with moisture-conditioned nitrogen to conserve the oxygen scavenger. For a detailed application guide, consult Maekawa and Elert (2003).

Advantages

Anoxia can be performed at room temperature (>20°C) in clear film or metalized film plastic bags. Long-term storage in anoxia bags significantly protects against reinfestation and other deleterious agents such as airborne contaminants, water, humidity swings, etc

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Disadvantages

Effectiveness is greatly reduced by moderately cool temperatures (less than 20°C). Anoxia in bags can be compromised by pinhole leaks or flawed seals. A few colorants are affected by a low-oxygen environment (chemical reduction), but this is mainly observed in long-term storage, not in the time span needed for pest control.

Controlled atmospheres (CO_2)

Expose objects for 1–3 weeks in atmospheres that contain carbon dioxide (60–90% CO_2 by volume induces fatal hypercarbia in a useful time period). Wood borers are commonly the most tolerant to hypercarbia, and require longer exposures. Contain CO_2 in a rigid enclosure (fumigation chamber) or in a flexible enclosure designed for fumigation with CO_2 (Warren 2001).

Advantages

Carbon dioxide fumigation works in the presence of any remaining oxygen; therefore, fumigating large objects is generally not compromised by pinhole failures in the container, provided overall gas concentration and circulation are maintained.

Disadvantages

Effectiveness is greatly reduced by moderately cool temperatures (less than 20°C). Carbon dioxide is registered as a fumigant and is an asphyxiant hazard to humans. Proper detectors and procedures are required. Carbon dioxide is a penetrating gas, affects mammalian physiology in low-percentage concentrations, and is easily adsorbed by concrete. Enclosure must be designed specifically for holding CO_2. Appropriate life-safety measures must be observed. Longhorn beetles are very tolerant to elevated CO_2.

CCI Technical Bulletin Nº 29.

Recover

IPM activity should be undertaken by a pest control coordinator who has been given the responsibility and resources to make this improvement in a facility's managerial practice (Figure 10). Without central coordination and continuity, pest problems are exacerbated. Actions that assist recovery from pest attack lists the common situations that occur after a pest attack and the applicable recovery method.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Actions that assist recovery from pest attack

Pest	Situation to recover	Action
Microorganism symbol Insect symbol Rodent symbol Bird and bat symbol	Lack of IPM plan.	Develop an IPM program that addresses the top risks to your facility, ensures subsequent incidents will be detected early, and ensures appropriate detection steps are taken. Continue to integrate pest management practices into the standard operation of a collection's care. With this integration, a pest infestation can be reduced from a crisis or chronic level to a nuisance level.
Microorganism symbol Insect symbol Rodent symbol Bird and bat symbol	Sanitation and remedial cleaning after events.	Rodent infestation is strongly related to human food use and waste. As well, other pests are attracted to spilled food and waste. Ensure program staff clean halls immediately after events, including food service, and remove garbage. Budget such clean-up into rental agreements. Monitor and facilitate compliance.
Microorganism symbol Insect symbol Rodent symbol Bird and bat symbol	Sanitation and remedial cleaning of infested areas.	Reduce the chance of false warnings of infestation by cleaning up after previous infestations, removing insect bodies, etc. Add relevant information to records about extent of infestation, damaged objects, likely source, and cost of recovery in time and money.
Microorganism symbol Insect symbol Rodent symbol Bird and bat symbol	Record the cost and efficiency of all methods used.	During treatment of an infestation, losses to collection, time expenditure, cost of activities, and useful resources should be noted for future reference. In institutions where staff turnover is high, such records are valuable to help plan for future situations. Economic records can be used to underline the importance of ongoing IPM activities and to support budget requests.

CCI Technical Bulletin Nº 29.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Figure 10. Museum staff can integrate pest management ideas into everyday operations, or implement a special focus on IPM when serious incidents are discovered. Integrating pest management principles into operations is a balance between over-concern on one hand, and being driven by a pest crisis on the other.

Control Strategies

The sample strategies for mitigating the effects of the main pest subtypes (Basic control of typical high, Intermediate control of typical high and moderate risks, Advanced control of all perceived risks) integrate site, building, fitting, and procedural elements. They focus on key elements in a Canadian context. Consult Pinniger (2004) and Strang and Kigawa (2006) for guidance in IPM program design. The latter has been adapted to this document as an IPM program guide based on control levels 0–6.

Basic control of typical high risks

Pest	**Strategies, activities, and infrastructure**
Microorganism symbol	Dehumidify to below 75% RH in seasons of warm humid weather (particularly during the summer months), and preferably to below 65% RH for year-round storage. Lower humidity strongly limits growth potential. Lower temperature and low humidity swings further limit growth in other seasons. A refrigeration-based dehumidifier will be adequate if its capacity exceeds or matches the room volume and the room is closed to the outside environment.
Insect symbol	Eliminate easy access to all foodstuffs. Use pest-resistant containers to protect vulnerable objects. Schedule an annual visual inspection for signs of insect activity in stored collections in late summer or autumn. Respond to these findings with control methods such as bagging or using a household chest freezer. Quarantine and possible treatment is advisable for new acquisitions. An annual low-temperature treatment

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	is advised for chronically exposed, high-vulnerability items (e.g. furs on interpretive display in historic houses).
Rodent symbol	Eliminate easy access to foodstuffs. Close all exterior gaps, leaving no opening larger than 5 mm. Shield vents with heavy gauge, non-corroding wire mesh. Do not compromise critical ventilation by sealing it with panels, ensure air flow remains adequate. Ensure attic and foundation gaps are also closed to at least 5 mm to prevent climbing or burrowing mammals from entering the building. Late autumn entry into buildings by rodents seeking winter shelter is a common behaviour, so pay attention to signs of rodent activity in this period. Respond with a trapping program combined with improved enclosure of the building, to reduce internal rodent population.
Bird and bat symbol	Repair, close, or install wire mesh on all exterior gaps used by bats and birds to enter a building (leave no opening larger than 5 mm, as per rodents). Use bird netting to block access to exterior roosting sites. Block potential nesting sites, but be sensitive to the animal's nesting dates if it is a protected species. Canadian laws protect bats and songbirds from human predation. While local regulations may allow removal from private property, species under pressure benefit from undisturbed breeding seasons, after which enclosure of a nesting space can take place. Likewise, winter hibernation of bats should also not be disturbed; therefore, close the roost's entries during April, or any time from October to November (Strang and Dawson 1991b).

CCI Technical Bulletin Nº 29.

Intermediate control of typical high and moderate risks

Pest	**Strategies, activities, and infrastructure**
Microorganism symbol	Dehumidify to below 65% RH year-round to eliminate mould and bacterial growth in interior spaces. However, in the north temperate zone, winter humidity levels of heated, occupied buildings will have to be closer to 30% RH to avoid potential mould growth inside insulated wall cavities unless a thoroughly intact vapour barrier is installed. Filtration of fresh air using standard HVAC system (MERV 14 air filtration) (Tétreault 2003) reduces spore concentrations. Install water detection alarms to alert staff if water pooling or flooding happens in susceptible zones of a building.
Insect symbol	Use adhesive traps in key locations as a means to conduct a quarterly inspection for insect activity. Conduct an annual visual inspection of collections. Use a household chest freezer as a quarantine treatment method for acquisitions and loans (bag objects).
Rodent symbol	Use an interior trapping program combined with effective blocking to detect and control rodents. Avoid using poison bait stations because poisoned rodents and some baits support insect pest life. As well,

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

	rodents are able to move poisoned bait to other locations despite careful design of the station.
Bird and bat symbol	Control as described in the basic level recommendations.

CCI Technical Bulletin Nº 29.

Advanced control of all perceived risks

Pest	**Strategies, activities, and infrastructure**
Microorganism symbol	Use high-efficiency HVAC system air filtration (MERV 15 or higher air filtration) (Tétreault 2003) to lower spore concentration and mitigate any building flooding, or HVAC system-failure-induced mould risk.
Insect symbol	Hold food waste in a coldroom (e.g. a stipulation in the Quebec building code) or immediately dispose of waste in external compactors. Metal and slab concrete building fabric is designed to control insect entry. Store high-vulnerability, high-value items in hermetic or tightly sealed cabinets or containers such as jars, plastic boxes, or vials. Detect insect action by using adhesive trapping throughout the building, concentrating on high-risk zones. Conduct an annual complete inspection of collections and galleries for insect activity. Plot pest activity by mapping (methods range from paper records to using a Geographic Information System) to ensure control activities cover all sightings. Deliberately seal a collection storeroom to prevent insect entry. Design collection storage areas to be cooled to between 10 and 15°C to limit insect activity if collections are highly vulnerable and open shelving is common (e.g. herbarium, large mammal specimens). Routinely use quarantine accompanied by a response treatment (controlled atmosphere or thermal control method) for all objects acquired, on loan, or showing insect pest activity. Apply control methods to all objects in collections (e.g. from gnats to elephants). In large organizations, penalties for deliberate failure to comply with quarantine regulations may be needed because of the high hazard presented by non-compliance in stored and vulnerable collections or by the cost of remediation.
Rodent symbol	Install rodent barrier doors (tight closure, metal fabric). Control exterior conditions, such as rodent-proofed garbage compactors, or good neighbourhood sanitation. Implement a detection program as stated in the basic and intermediate level recommendations.
Bird and bat symbol	Control as stated in the basic level recommendations.

CCI Technical Bulletin Nº 29.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Case Study 1: Rodents living in large city gallery

Mice infesting a gallery's "Donor's Room" kitchen, hundreds of feet from any collection storage, near open sculpture galleries and a main atrium, which are food event locations (Figure 11).

Figure 11. Kitchens are attractive to rodents, which can enter through a badly fitting pipe chase or by crawling under doors. Most rodent problems are associated with human food in buildings. On the right, mouse feces can be seen in the cupboard. The access hole has been ineffectively plugged with crumpled paper.

Hazards:

- a donor could become ill from contact with a rodent-related, faecal-borne disease
- mice could nest in stored fabric items (e.g. interpretation program costumes, textile arts, object padding) if the colony becomes established

How the mice got there:

- holes through building fabric were larger than 5 mm, due to construction projects that opened up exterior walls

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

- outside mice colonies feeding on ambient garbage in an adjacent park were attracted to the building
- badly sealed city sewer or steam pipe connections, and gaps under emergency and loading bay doors provided entry routes

Short-term control measures

Loose foodstuffs were cleaned out of cupboards and placed in sealed food containers, and garbage was placed in closed containers. Daily garbage removal was instituted. The access point was located, and an open path through the wall along a sink drainpipe was sealed. Snap traps were set to kill mice in the room and adjacent rooms, which were connected by the pipe chase.

Long-term control measures

Entering the facility's monthly pest control contractor's records into a graph showed a steady, but constant, accumulation of rodents caught monthly over several years. So either a small number enters frequently and does not survive the trapping program, the internal population has limited mating success, or a sparsely deployed (non-public areas) poison baiting system may be working to limit exponential growth. However, improved exclusionary practices and continued trapping are required to cause the annual catch numbers to drop toward zero.

Case Study 2: Mould outbreak in a rural museum

Staff of a rural seasonal museum in a former community school building discovered mould and mildew on many objects and wall surfaces while preparing the museum for its spring opening (Figure 12). A persistent vandalism threat had forced them to board up all sash windows and external doors during the previous autumn closing. This act unwittingly changed the ventilation pattern of the building by restricting the air exchange rate. Damp spring weather added considerable moisture through a porous building fabric and the slab-on-grade concrete floor that was built on the site of a former wood-milling operation, which had left a lot of mill waste in the soil. The furnace was set to minimal activity in the core area during winter to prevent the pipes from freezing, leaving former classrooms unheated. Moisture in partially heated buildings moves from warmed areas and accumulates in cool areas. This situation, combined with the elevated internal humidity and warmer daytime temperatures for a couple of months before opening, encouraged mould spores to germinate on objects.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Figure 12. Mould often becomes visible as whitish spots, but other colours are common. Here mould is growing supported by the nutritional value of the oils on the leather buttons.

Short-term control measures

Opening an access door in the central corridor to a well-ventilated attic increased air extraction from the building and began removing excess moisture. This action of reducing compartmentalization and opening all inner room doors to allow ventilation through to the attic temporarily increased the fire spread hazard.

Long-term control measures

Use metal grills on windows to ensure security during the closed season (in place of the plywood sheathing previously used). Acquire and run dehumidifiers when the building is closed up (at a cost of buying and running the equipment). Portable dehumidifiers need a connection, such as a simple flexible hose, to a drain for unattended operation. Capacity of the humidifiers must match the enclosed building volume (Strang and Dawson 1991a). Dehumidifiers operate less often during the winter season (their performance is constrained by low temperatures), but are entirely adequate during the critical spring season. Open the building earlier in the season to ensure effective ventilation and to detect problems earlier (increasing staff time on site). Clean objects according to a conservator's recommendation, and hard-surface clean with biocidal detergents.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Case Study 3: Insects infest donation to a civic museum

Clothes moths were found infesting a newly acquired uniform collection of hundreds of items (Figure 13). The civic museum has no money or permanent infrastructure for treatment. It would deaccession and dispose of the collection rather than risk spreading an infestation by incorporating these objects into the collection without treating them.

Figure 13. Case-making clothes moths can be difficult to see because their cases are made from the material they are eating.

Short-term control measures

Quarantined the collection by sealing objects in polyethylene garbage bags, leaf bags, or equivalent barrier containers. Clearly labelled the bags with warnings: "PEST QUARANTINED ITEMS — DO NOT DISPOSE" or "MOTH INFESTED — DO NOT OPEN". Also annotated the bags with the responsible person's name, contact information, and date of enclosure. This adequately contained the hazard until treatment could be arranged.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Long-term control measures

Used outdoor winter conditions to cold-treat the entire collection on the museum rooftop, taking advantage of an elevator shaft superstructure that provided a shaded north exposure. The quarantine-bagged collection was set on tarpaulin-covered pallets that eliminated the possibility of contact with the roof, which could have conducted heat into the objects.

Wrapped in another tarp for protection against strong wind, the objects were exposed to low temperatures (predicted weather: less than −20°C all day for several days). The collection was exposed for as long as possible: minimum of 3 days for clothes moths, 1 week preferred. The collection was brought indoors, rewarmed overnight, and checked for living insects. Objects were cleaned before they were incorporated into the collection.

As an alternate strategy, infested objects could be treated one-by-one in borrowed space in household freezers while keeping all other objects quarantined in bags to prevent the pest's spread. Sometimes commercial freezer space can be arranged on a gratis basis or a refrigerated truck can be rented. Responding to this volume of infestation could fall under disaster planning and would profit from prior arrangements for services.

Case Study 4: Wood borers in rural agricultural museum

A rural agricultural museum's displayed wooden farm machinery and tool collections were severely affected by widespread lyctid wood borers. A local pest control company wanted $300 to look at the problem — money the museum did not have.

Short-term control measures

Consulting with the Canadian Conservation Institute (CCI), the provincial conservation advisor oversaw the construction of a safe and effective heat disinfestation chamber using volunteered professional services at the museum (Figure 14). Donated materials and air heating equipment were assembled on site. Staff ran several loads of mixed large and small items through the system, one load per day for about 7 hours under constant surveillance. The moisture balance was maintained by the high volume of material self-buffering the contents in the sealed chamber (Strang 2001).

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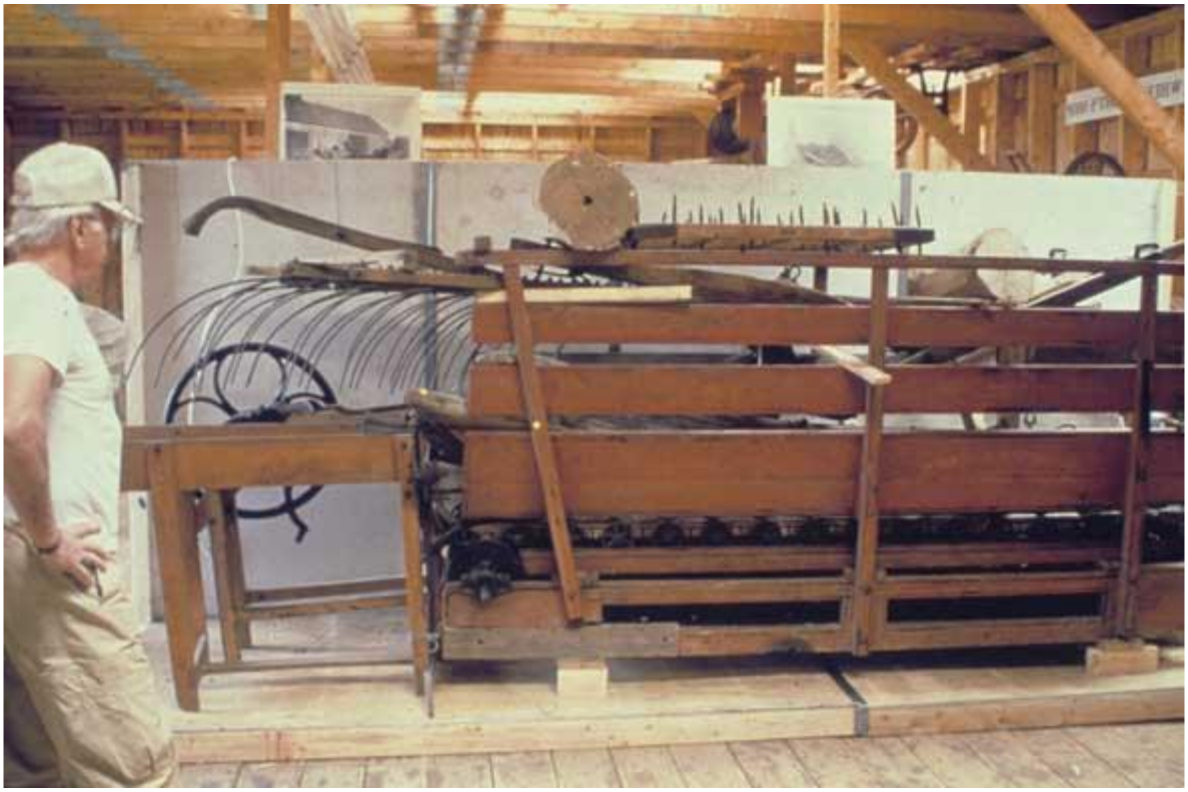


Figure 14. Objects inside an insulated plywood box that was heated with air and kept between 55 to 60°C until the thickest pieces were heated through. This treatment kills all insect life.

Long-term control measures

Because lyctid wood borers are found in the surrounding region and are associated with dead timber, any further pest activity in subsequent years should be noted immediately and the affected pieces put through low-temperature control or an in situ heat treatment. The museum and the objects should be thoroughly cleaned regularly to see if any insect frass piles are forming. Structural inspection of the building should be done to ensure that any hardwood elements are not affected by insect pests.

Application guides

The following application guides are included to help an institution create a first-time IPM program. These guides were designed to be adaptable to a wide variety of situations. Specific pest eradication procedure guides are also available that demonstrate how to simply and correctly follow the various steps.

Designing an IPM program

This section outlines a basic IPM program. Each table describes a recognizable situation accompanied by IPM recommendations. It can be used to make a rapid survey of a current state and to note items to incorporate into a collection's IPM plan.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Levels 0–6. Doing an IPM survey to create a plan of action

Photocopy the tables so you can mark them up. Determine the nearest level to your situation by matching it to the table's headline description. Read the left column headings of Site, Building, Portable Fittings, and Procedure to see if these descriptions are roughly applicable to your situation. Use a highlighter to mark features that are present in your situation (left-side column). If the terms in the table matching your situation (level) are not applicable, search through adjacent tables to find more appropriate terms to capture the breadth of the situation across your holdings and highlight them. The actions in the right-hand column (Plan B), which are listed near the items you highlighted, are a guide to reasonable activities or modifications that will help ensure a better degree of protection.

One response to pest problems would be to move the collection from its existing level of enclosure to a higher level. Often this is an institution's ideal "Plan A" because it solves many problems in collection care, exhibition, etc. There are degrees of a "Plan A" response. A building upgrade providing new or additional collection storage is a much costlier proposition than a simpler "Plan A" response of moving wood wagons from field display to a place underneath an existing shed roof. Both would provide benefits to long-term preservation from biological and other deterioration mechanisms, but would have different residual vulnerabilities.

The Plan B column was created to show how one can fight back against pests in the given situation if a "Plan A" solution must wait or cannot be done. Using the suggestions given under Plan B, determine if the described activities are being performed, or if the suggested modifications are present in your facility. The Plan B columns were designed to include remedial suggestions where they would most likely be effective and not cause undue effort at that level.

The prognosis and expected deterioration are given as examples of what the uncontrolled situation might result in and the changes that might result from an IPM program or pest control treatments.

For a full description of the approach and rationale behind these tables, consult Strang and Kigawa (2006).

Level 0 — Outdoors with unrestrained access by harmful agents

Starting from a situation of no preservation steps taken, this is the base level from which to evaluate the effectiveness of any improvements to block pests. Plan B presents the first steps to reduce the effects of pests in this situation.

Examples

Building exterior, totem pole, public sculpture.

Plan B

None

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Site

Outdoors, rural or urban, may be sheltered by trees, buildings, or landforms. May be well or poorly drained. May be windswept or sheltered. Urban sites are likely public spaces. Rural sites may be remote with little visitation.

Plan B

Some environmental modification may be considered if the site is clearly harmful; for example, cutting back encroaching growth that physically disrupts structures, shelters pests, or induces higher moisture content by casting shade; cutting back clinging vines that disfigure, obscure, create a fire risk, etc.

Building

No exterior enclosure; fully exposed to year-round material weathering; object sitting directly on ground.

Plan B

There is considerable preservation justification for moving objects under shelter. If that is not possible, in situ techniques should be considered. Use bird netting or enclosures made of sheet material (metal, tarpaulins) to block pests if the object is open to weather, collecting detritus, or housing animals (in the case of large machinery, derelict buildings). Install angled raincaps (e.g. on pole tops, exposed beam ends) where possible to reduce roosting and bird detritus that induces rot.

Portable fittings

None

Plan B

Separate rot-prone objects from the soil they are resting on: use compacted gravel; paved surfaces; a fungicide/insecticide-treated wood shoring; a short concrete plinth; or a moisture barrier (such as a sheet metal layer between post and pillar; where the sheet metal protrudes horizontally, bend it downward to avoid conducting splashed water into the joint). Use these solutions to reduce ground contact, slow fungal attack, and reduce burrowing insect access. Metal shields, which divide wood from foundation elements, will force termites to run their shelter tubes across the shield where they are readily detected, or carpenter ants to walk along visible surfaces, which improves detection.

Procedure

None. Abandoned to fate.

Plan B

Routinely remove grime, soil pockets (which are a site for rapid biological activity), and all surface growths such as lichen, mould, moss,etc. Examine object for insect infestations, especially wood borers. Wood-borer activity can lead to structural collapse. Use residual pesticides or fungicides when warranted.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Sealing wood to reduce moisture absorption is most effective when the sealing agent is applied on a smooth surface, or on minimally weathered new wood. Deteriorated surfaces allow easy paths to form that water can then follow into the interior. This condition supports systemic fungal attack. All surface treatments need to be periodically repeated as the surface of the object weathers. Be aware that borate fungicide and insecticide treatments can be washed away from wood surfaces. However, the solid borate rods and chips put into holes bored into timber do rely on wood moisture to migrate further into the wood and confer protection. Preservative fungicides and insecticides may stain surfaces; therefore, test first. Subterranean sections of an object near the surface of the soil can be excavated, approved fungicide applied, and surface drainage improved. The most rapid pest attacks generally occur in the soil just above the water table, where the soil is still oxygenated. Thank people for their contribution when they detect problems and report them to you.

Prognosis

Open to maximum algal, fungal, rodent, and insect attack. Chronic bird and bat roosting. Systemic effects due to pest attacks on the materials they are adapted to use.

Plan B

Reduced algal, fungal, rodent, insect attack, and bird roosting. A range of surface to systemic effects is still expected because the object is exposed to the elements, but the damage has been reduced because of detection and remediation.

Expected deterioration

Noticeable effect or damage in one season, as rapidly as what can happen to a dead tree, mammal, insect, or leaf. Colonization of more resistant items by algae, moss, fungi, and plants in a few years. Anticipated effects show within a few years on robust items, and within a few days on delicate items. Self-sheltered parts of the object will retain features as noted in Level 1, but will eventually succumb to harmful agent attacks.

Plan B

Noticeable effect or damage in one season. Anticipated effects show within a decade on robust items, and within a few days on delicate items. Self-sheltering parts of object will retain features as in Level 1, but will eventually succumb to harmful agent attacks.

CCI Technical Bulletin Nº 29.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html


Level 0. A totem pole outdoors.

Level 1 — Roof or tarp only

Basic shelter from rain and overhead sun is provided by an architectural element, an applied covering, or a self-sheltering part of the exposed object. In your action plan, include appropriate action elements from Level 0, Plan B.

Examples

Poor enclosure in a wind-way or carport. Top of bject sheltered by a shed roof or tarpaulin cover.

Plan B

None

Site

Outdoors, rural or urban, may be windswept or sheltered by trees, buildings, or landforms. Site may be well or poorly drained.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Plan B

Some environmental modification may be considered if causing harmful effects (e.g. cutting back encroaching growth that shelters pests and induces higher moisture content by casting shade, or cutting back clinging vines that disfigure a structure or object). Eliminate obvious nearby pest attractors such as open garbage containers. Ensure roof is capable of withstanding a maximum snow and wind load.

Building

A roof or tarpaulin overhead with no complete wall. Structure protects against direct rainfall, prevents extensive fungal attack, and limits any mould-requiring boring insect attack. However, the structure will attract nesting birds, rodents, and insects seeking shelter. Does not stop rodent, bird, or insect access.

Plan B

A roof must extend over the object to protect it from slanting rain. Note that damp air rises because it is lighter than dry air (water vapour is lighter than the oxygen and nitrogen gases that make up most of the air). Therefore, if tarpaulins are used to enclose an object, ensure that there is ventilation near the top ridge so that there is no prolonged entrapment of high humidity. A plastic tarp that does not ventilate at the ridge forms a dome over the object, and traps dampness underneath. You may have to reduce the moisture source from the ground or a slab on grade concrete floor by first laying a moisture barrier tarp underneath the object. Bird netting or spikes used where possible deter roosting, which in turn reduces detritus on a structure or sheltered objects. Coordinate the building of wire screen enclosures or cages with the provision of physical protection needs from vandals, climbers, etc. (i.e. improve security and pest-proofing simultaneously). Treat wood in contact with the soil with fungicides.

Portable fittings

None, contents of the enclosure rest directly on earth or gravel, or are semi-buried.

Plan B

Where possible, separate objects from soil or gravel by using a short plinth, or insert a moisture barrier to reduce moisture from contact with the soil. Ensure the barrier drains properly so that puddles do not form against the object.

Procedure

No pest-control procedures other than the beneficial contributions of the original construction (e.g. mineral shingles, paint). Little site sanitation other than what is due to wind and weathering processes.

Plan B

Consider improvements recommended in Level 0, Plan B.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Prognosis

Rodent or bird contamination in 1 year, structural insect attack in under 10 years, surface mildew within 10 years. Many harmful pests still have widespread access to sheltered objects.

Plan B

Noticeable extension in the lifetime of smaller-dimension wooden elements by using remedial fungicide treatments, or breaking the wood's contact with soil, especially for wood species that deteriorate rapidly. Reduction of disfiguring animal nests and some wood-boring insects. Elimination of most structural fungal attack due to the low moisture content of sheltered objects. Surface mildew, moss, lichen, or algae are still present asa risk in humid environments.

Expected deterioration

Noticeable effect or damage in one season. Anticipated effects show within a decade to a century on robust items, within several years on soft materials, and within months on delicate materials. Self-sheltered parts of the object will retain features as noted in Level 2.

Plan B

Noticeable extension in the lifetime of wooden elements due to remedial fungicide treatments. Noticeable effects show within several years on soft materials, and within months on delicate materials. Self-sheltered parts of object will retain features as noted in Level 2.

CCI Technical Bulletin Nº 29.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Level 1. A tarped agricultural machine.

Level 2 — Roof, walls, and loose-fitting doors

This level offers more complete shelter from the elements. Contents may be exposed to wind-driven precipitation, oblique sun rays, excessive wind and wind-blown soil, snow, spores, and seeds. In your action plan, include appropriate elements from previous levels.

Examples

Poor to fair enclosure: outbuilding; shed; poorly maintained house.

Plan B

None

Site

Commonly rural, sometimes urban. Drainage may have been improved by a small rise in elevation under or against foundations. Subterranean foundation is leaky. Structure may be sound if roof has been maintained, otherwise structural damage is expected.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Plan B

Where possible, clear vegetation away from walls to reduce moisture damage and prevent encroaching plant roots from damaging the building foundation. Remove nearby dead timber to lower the incidence of wood-boring pests and deadfall hazards to structure. Improve drainage if water pools against the foundation or seeps into the building after a rainfall.

Building

Walls, wood, porous cladding, basic doors with gaps, rammed earthen floor, planks, plywood, gravel, asphalt, or separate concrete pad. Will not stop determined burrowing or gnawing pests because structural materials and wall construction are easily compromised. Protects against wind-driven precipitation, thus halting major fungal attack. Does not block insects because there are gaps in the structure. May limit large rodent and bird entry, but gaps allow small animals to shelter in the building. May attract roosting and nesting birds into eaves and insects into the building fabric.

Plan B

Install bird netting on the eaves or wire caging over openings where possible to reduce animal entry and subsequent detritus collecting around and in the structure. Coordinate construction of enclosure with physical protection needs (e.g. improve security and pest proofing simultaneously).Improve or fix exterior sheathing if it has been compromised.

Portable fittings

Contents resting on hard floor can become damp from permeating ground moisture on which fungi could grow.

Plan B

Rudimentary shelving limits moisture transfer from the damp ground or building foundation pad to the object. Putting objects up onto shelves will lower chance encounters with some pests. If appropriate shelving is not available, at least use heat-treated pallets, or lumber wrapped in plastic sheeting, to separate objects from contact with the moisture in an earthen floor. To avoid damage from minor floods and persistent moisture, elevate large, heavy items off the ground, and rest them securely on cast concrete pads or on treated timber blocks that have a moisture barrier underneath that prevents moisture being conducted into objects. Prevent heavy objects from sinking into the soil, as this would allow direct access by microorganisms and other wood-destroying pests.

Procedure

Animal nests removed. Groundskeeping around building consists of annual to monthly cutting back grass and foliage.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Plan B

Routinely sweep interior spaces to eliminate wind-blown detritus and spider nests. Immediately remove wasp nests and bird nests. Use fabric (moisture permeable) tarpaulins as drapes over complex, hard-to-clean objects to reduce dust accumulation, prevent flies from spotting surfaces, allow moisture to dry after humid periods, and help reduce surface mould growth.

Prognosis

Expect fly specks, rodent invasion, insects grazing or crawling over stored materials, especially in cluttered, unchanging, unexamined areas. Water-staining and possible fungal attack after heavy rain accompanied by winds. Pests have free range, so all contents can be affected.

Plan B

Reduction of disfiguring animal nests by removing them and early remediation of pest attack through targeted pesticide use or physical methods.

Expected deterioration

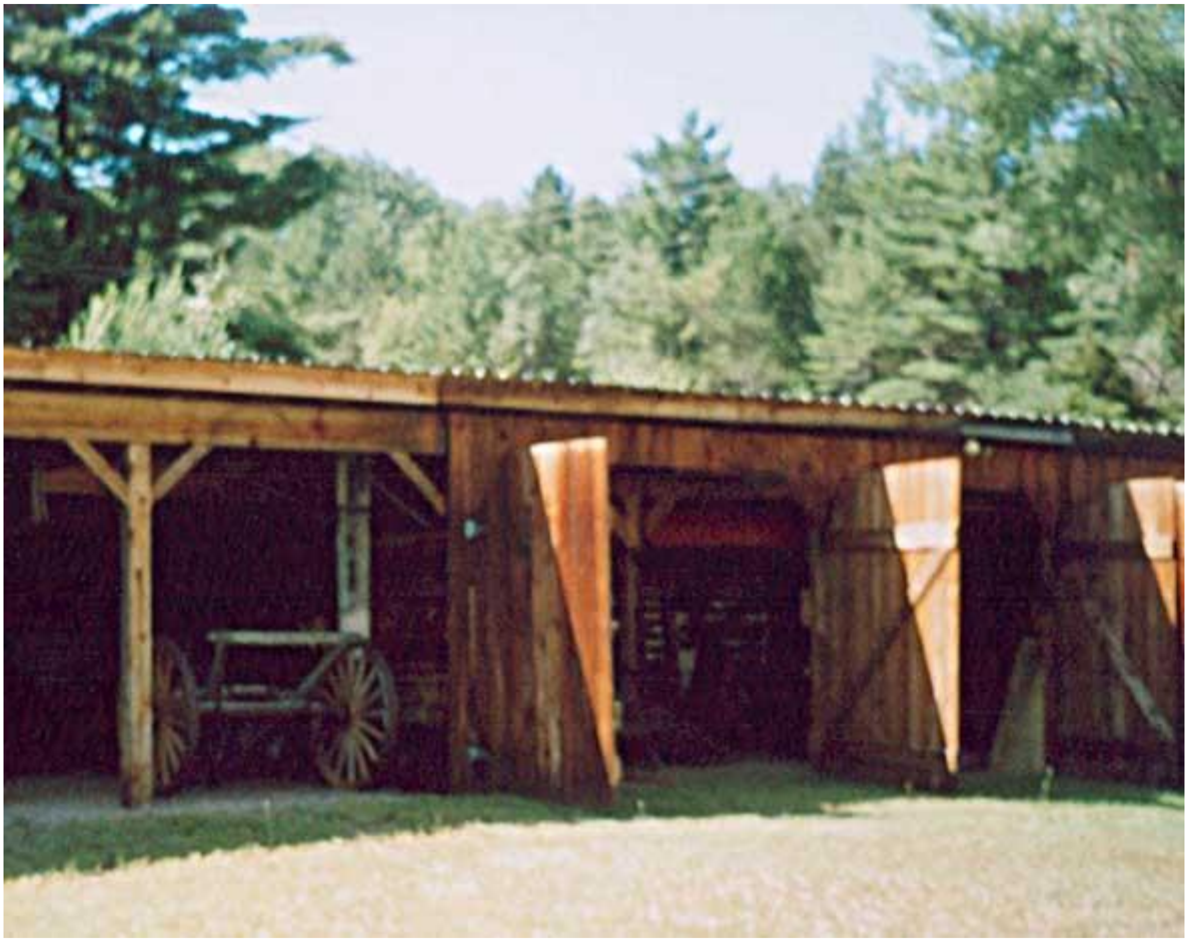
Anticipated effects show within a century on robust objects, within a decade on soft materials, and within a year on delicate materials.

Plan B

Reduced frequency of many insect attacks compared to lesser shelteredÂ situations. Minimal structural microbial activity, and greatly reduced surface activity.

CCI Technical Bulletin Nº 29.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html



Level 2. A drive shed on gravel.

Level 3 — Basic habitation

Human housing that has reasonable protection from the effects of climate and coarse control of the interior environment through basic heating or ventilation. In your action plan, include appropriate elements from previous levels.

Examples

Fair enclosure: western-style housing up to the early 1900s; public buildings such as churches, palaces, etc. Average maintained historic civic buildings, temples, shrines.

Plan B

None

Site

Garden landscapes, walkways, lanes, streets. Drainage into open ditches, roadways, rudimentary sewer

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Plan B

Limit the growth of trees and shrubs against the structure to protect vulnerable foundations against damage from encroaching plant roots.

Building

Reasonable attempt to fully enclose the building to protect it from bad weather to make a liveable building with some comfort during the annual climate cycle. Gaps generally small if building has basic heating, but exterior cladding may allow determined or occasional rodent access. Has single doors for entry, loose-fitting sash windows, possibly no screens. Internal partition walls have crevices along the floor that can house insect life. Open fireplaces, flues, hollow space under floors, and roughly finished attics allow bird, rodent, and insect access into structural voids. Some natural ventilation is possible to alter interior temperature or humidity, but there is no air conditioning system.

Plan B

Use screen doors and screens on windows to reduce insect entry and allow ventilation. Reduce structural gaps and spaces around habitually used openings (doors, windows) to under 5 mm to limit rodent entry. Ensure eaves trough has outflow pipes to carry water well away from foundations, which will reduce potential for mould growth. Screen unused flues at the roof level to block bird and insect access. Use heavy gauge, plastic sheet “soil covers” over enclosed earthen-floor crawl spaces. Ensure good, screened ventilation of this space to further reduce its humidity, otherwise wooden structural elements will be susceptible to fungal and insect attack.

Portable fittings

Some objects are displayed inside the building as they were originally used (historic interior), and others are stored in closed rooms on shelves, in slightly or fully open boxes. Some objects may be stored in cabinets for security, but the enclosure’s resistance to pests is generally poor.

Plan B

Place objects vulnerable to insects in well-sealed display or storage cabinets (ensure that any gaps are less than 0.3 mm). Consider operating portable dehumidifiers to restrict relative humidity to under 75% over a short, damp period (i.e. 2 months), and under 65% in year-round, high-humidity climates. Consider using polyethylene bag enclosures (installed during dry season), or fabric covers for soft items in storage to reduce pest incidence. Delicate items should be placed in lidded boxes or cabinets.

Procedure

Spring and fall cleaning, household vacuuming, and dusting exhibits may also occur when build-up of dirt is noticed.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Plan B

Do not place objects in underground areas if you cannot ensure good ventilation or flood control. Inspect attic and basement areas annually for severe pest problems. These spaces often fulfil a pest's needs more than the inhabited floors do.

Prognosis

Multiple rooms can be affected, chronic outbreaks of paper and fabric pests could be supported. Storage in damp basements or hot attics are retrograde choices for object survival.

Plan B

Reduced chronic fly and dermestid problems because of increased control over attic space. Reduced silverfish and mouse problems because of increased control over conditions in basement and crawl spaces.

Expected deterioration

Anticipated effects appear within an equivalent time to the building's lifetime on robust objects, within decades to a century on soft materials, and within years on delicate materials.

Plan B

Reduced rodent, insect, and fungal damage because of increased sealing of the building and routine sanitation activity.

CCI Technical Bulletin Nº 29.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Level 3. A schoolhouse turned into a centennial museum.

Level 4 — Adapted commercial

Adapted civic structures built for large-scale inhabitation, industrial processes, or business activities. Historic structures that possess elaborate architecture. In your action plan, include appropriate elements from previous levels.

Examples

Good enclosure: basic professional, commercial, or civic building adapted to museum, archive, or gallery use.

Plan B

None

Site

Drainage ensured close to foundation walls, but overall site may not yet be adapted to 100-year cycle of weather extremes, or is affected by adverse elements from neighbouring properties, which are strong pest attractors.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Plan B

Include in the site development planning the means to reduce the possibility of flooding and to eliminate places where rodents could live.

Building

Often has a mineral-based exterior surface (e.g. jointed stone, brick). Has multiple doors to the exterior, a mudroom, or a divided entrance hall. Single layer of doors, such as emergency exits, are sealed tightly with brush strips, rubber blades, and rodent-proof metal. Structure has an HVAC system system for air conditioning, heating, and forced air movement.

Plan B

Improve sealing of doors, windows, and other perforations to prevent pest access. Improve interior partitions to limit rodent travel by reducing gaps under doors and screening perforations.

Portable fittings

It has exterior garbage bins or a purpose-designed loading bay garbage collection area (the bay is inside one exterior door, but has a well-fitting inner door that cuts the bay off from the corridor). More extensive use of display cabinets, which may not all be insect proof but greatly lower the incidence of insect infiltration. All collections are placed on shelving or on pallets. There may not be easy access for pest inspections throughout the storeroom because of overcrowding. Hallways are also used as overflow storage.

Plan B

Create an enclosed space for quarantining incoming goods and artifacts as well as for disinfesting new acquisitions. Obtain a chest freezer, CO_2 fumigation bubble, or nitrogen treatment chamber. Train several staff to properly and safely use this equipment and to comply with regulations. Incorporate inspection needs when rehousing collection.

Procedure

Basic visual inspection of collection arising from its use rather than from systematic inspection. Few traps used in areas with major exterior openings. Annual storage room sanitation procedures limited to vacuuming, but only in corridor spaces, not under lower shelves. Gallery cleaning more frequent, but does not keep up with dust, litter, hair, etc. that is deposited in restricted spaces.

Plan B

Conduct annual cleaning, reduce clutter, vacuum under shelving, inspect rarely accessed collections. Quarantine and eradicate pests before objects are introduced into collections. With an established IPM program and a low internal pest incidence, new collections are the highest risk for introducing infestation, along with used packaging and food service activities. Disposing of garbage (especially foods) on a daily basis and immediately cleaning spills is necessary. Hire a pest control operator (PCO) to clean public food areas. Hire a PCO to clean collection areas only if heavily infested and in need of remedial action

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(baseboard sprays only, avoid area fumigation or pesticide application on objects). Use a trapping program to detect pests. If the building is reasonably tightly enclosed, regular trapping will tell more about what is going on in collections than what is crawling into the building that day.

Prognosis

Expect local outbreaks of pests, caused from importing pests along with objects rather than from building infiltrations. Insects are more commonly imported than rodents.

Plan B

Reduction of chronic textile, fur, and skin/hide pest infestations. Annual levels may be chronic, but should occur less often and with less severity.

Expected deterioration

Anticipated effects show up within the equivalent time to the building's lifetime on robust materials, within a century on soft materials, and within decades on delicate materials.

Plan B

Less frequent infestation by insects than seen in previous levels.

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https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Level 4. A former bakery turned into a technology museum.

Level 5 — Purpose built

Building designed as a museum, gallery, or archive accompanied by increased planning that integrates policies and features to include pest control with control of other agents of deterioration. Include appropriate elements from previous levels.

Examples

Purposefully designed as a museum, archive, or gallery. Improved enclosure meets preservation requirements. Enhanced commercial construction that provides spaces and features designed to store and display collections.

Plan B

None

Site

Site planning includes perimeter control of neighbouring risks by environmental modification (e.g. creating buffer zones, limiting pooling of water, and pruning dense foliage to lower fire hazard).

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Plan B

None

Building

Designed with consideration for pest control such as providing a room to support freezers, controlled atmosphere fumigation, and quarantine needs. Smooth flooring, coved junctions with walls for easy cleaning. Light-coloured finishes and good lighting to aid pest detection. Pest-resistant exterior wall materials and fewer crevices when built in order to lower HVAC system losses and reduce wall moisture issues.

Plan B

Crevices discovered to be housing insects are caulked with appropriate sealant. Exterior window seals are maintained promptly to exclude wall moisture, and improvements are made to seal all exterior doors when flawed installation is discovered or materials fail. Improved HVAC system filtration to “MERV 9” level to eliminate mould spore and pollen transport.

Portable fittings

Intensive use of protective cabinets increases the need for planned visual inspection. Many objects not on display, so there is a delay in finding outbreaks without a planned inspection. Little consideration given to cleaning underneath displays over the long term of a permanent gallery's life. High traffic leads to accumulation of litter – some of which can support pest life. Enclosed exhibits constructed to a level of tightness that excludes insects (gaps of 0.1 – 0.3 mm). Have capacity to treat routine volume of artifacts in walk-in freezers (−25 to −30°C) or controlled atmosphere fumigation.

Plan B

Exhibit techniques that use showcase furniture or permanent diorama constructions are examples of objects that can provide hiding places for pests near areas of high visitor traffic. Consider reducing these long-term hazards for eventual pest colonization by designing for ease of access into the display and into hidden spaces underneath. Periodically clean these enclosures to remove detritus (fibre, dust, food particles, etc.). Promptly remove food garbage, which should be in closed containers and emptied daily, to reduce support for mice.

Procedure

Systematic, detailed inspection for pests. Comprehensive use of adhesive traps for pest detection. Bird proofing of structure. Commercial pest control operator (PCO) to disinfest the on-site restaurant. Permanent cleaning staff and security are not trained in IPM practices. All new acquisitions are subject to quarantine, inspection, and pest eradication processes. International loans of objects must be packaged in materials that support current import/export restrictions designed to limit the spread of wood pests. Only certified wood (heat treated) or exempted wood products used in packaging.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Plan B

In larger institutions, consider using a zoned IPM system to indicate the most vulnerable areas needing special precautions and protection against pests. Visually inspect the most sensitive and valuable objects annually. Give all permanent staff basic IPM training to sensitize them to pest problems and methods of prevention. Elevated degree of storeroom sanitation is recognized as an effective pest-reduction activity. Clean non-traffic areas, including under-shelf spaces in storage rooms, annually.

Prognosis

Sporadic outbreaks associated with non-collection areas and events. Older storage cabinets may continue to show higher incidence of infestation because they are more porous, and because pests live in high-density arrangements of cabinets.

Plan B

Sporadic pest problems occur with new collections and returning loans.

Expected deterioration

Anticipated events show up in a similar time on robust and on soft objects, and within a century on delicate objects

Plan B

Less frequent sporadic pest outbreaks due to early intervention and effective remediation.

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https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Level 5. A century-old city block square museum.

Level 6 — Preservation designed

A collections facility whose primary function is long-term preservation. Provides an excellent enclosure, with multiple layers that block routine hazards, and is designed to reduce calamities. In your action plan, include appropriate elements from previous levels.

Examples

Purpose-designed preservation enclosure; full spectrum of pest-reducing features incorporated such as a refrigerated herbarium collection building, an ethnographic fur storage room, and extensive use of tightly sealed cabinetry for all collections.

Plan B

None

Site

Construction conforms with the need to fully manage for an expected 100-year cycle of weather extremes. Exterior plantings controlled, and sanitary perimeter managed as noted in Level 0, Plan B. Use of food processing plant techniques such as gravel borders on geotextile (engineered fabric underlays that control soil movement) to lower rodent pressure (Imholte 1984). Exterior wall sheltered under protective eaves as noted in Level 1, Plan B.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Plan B

None

Building

Design clearly based on collection preservation needs. Construction phase requires establishing trust between conservation and construction professionals to discuss these needs when details are decided and executed. A perimeter corridor buffers storerooms from effects of the outside environment better than a single wall. Poured concrete, slab or wall junctions sealed and maintained. Storage areas separated from high human occupancy activities. Floor sweep on interior doors restricts insect movement. Installing pipe and wiring chases minimizes wall perforations. Holes are sealed with appropriate materials that maintain room-to-room quarantine. Built-in vacuum, or portable HEPA vacuum units, are used to control dust. Cabinets throughout the building are tightly sealed. HVAC system system has to be designed to eliminate particulate contaminants and spores if there is significant storage on open shelving. Pest-control facility near loading bay provides quarantine and treatment area including enough room to store travelling exhibit packaging. Cooled food waste and garbage storeroom.

Plan B

Equip HVAC system system up to MERV 13, which eliminates particulate contaminants including dust mite faeces. Plan cool room storage to inhibit insect motion and lower chemical deterioration rate (e.g. rooms kept at 15°C). However, this solution requires careful design, commitment to maintenance, and energy use. Construction project includes strict control of details, such as vapour barriers, due to the high performance expectations for the building's envelope. Structure and contents disinfested before occupation, which requires coordination of pest-control operations when the collection is moved in.

Portable fittings

Light traps positioned to draw insects out from loading bay. Bird curtains or shrouds connected to truck trailers block most pest access when doors are open. Appropriate system (−20 to −30°C freezer, controlled-atmosphere fumigation, heat chamber) for eradicating infestation of new acquisitions.

Plan B

Cabinet integrity protected by an annual inspection and maintenance plan. Near hermetic storage (e.g. film canisters) can be used for most valuable and vulnerable items in long-term storage. All disinfested objects sealed in pest-resistant enclosures, possibly refrigerated, possibly in an altered storage atmosphere. Walk-in storage freezers with back-up power supply used for routine pest control.

Procedure

Structural flaws promptly corrected, crevices caulked. Routine trapping near openings of each room and vulnerable collections databased and mapped for long-term analysis. Annual visual inspection of susceptible collections. Storage areas kept at temperature set primarily for human comfort (which does little to suppress pest growth). Contents are sterilized, sanitized, fumigated, cleaned, and inspected (depending on requirement for long-term storage) before being hermetically sealed or deposited in tight, pest-resistant containers. Bagged, in vials, or boxed artifacts all placed in pest-resistant cabinets. Visual

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inspections conducted to confirm integrity of seals and absence of pests on an annual basis. For refrigerated storage, all contents are sealed against refrigeration failure and moisture movement. A recovery plan is in place in case of mechanical failure. New staff are trained in IPM policies and methods. Maintain work relationships through an IPM committee and informal connections with the staff who encounter pests (security, maintenance, food services).

Plan B

None.

Prognosis

Few pest issues in storage areas. More found by floor trapping than by inspecting cabinets visually. A few pests found in gallery spaces due to human traffic and food service.

Plan B

Sporadic pest problems, mostly in new collections and on objects returning from loan.

Expected deterioration

Anticipated pest events are minimal over the presumed lifetime of the storage structure for robust to delicate objects. Long-term survival of objects is tied to cultural will to preserve the contents, structural integrity of the building, and energy to support necessary services.

Plan B

None.

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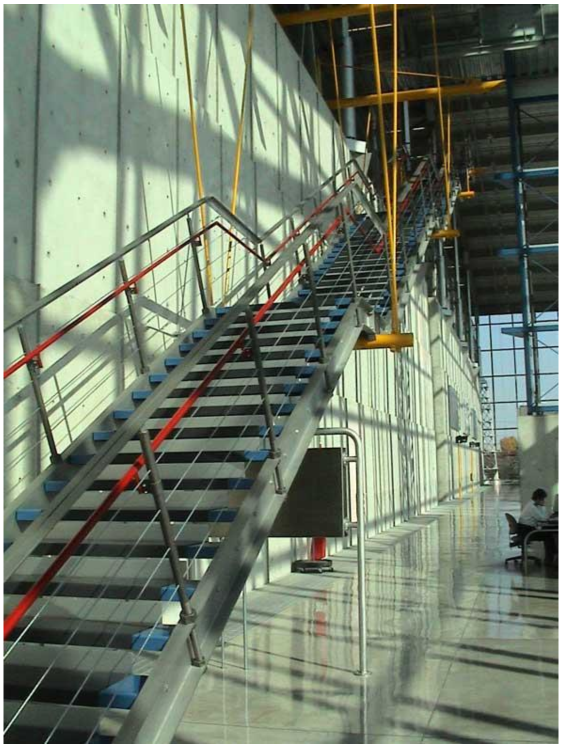
Level 6. A national archive designed as a building within a building.

Progressive scales of IPM components

Progressive scales of IPM components Column headings reflect activities and structural concerns that affect IPM in collection facilities. Use these headings to highlight elements your facility has. Notice the implied scale of improvement that is built into the previous Level 0 – 6 tables.

Each column in these tables is a scale, listing in incremental order the improved activities and features that are distributed across the levels (physical situations 0–6). These scales can be used as a brief, structured inventory of features and actions in your facility by highlighting elements that match your situation. The result is a summary "readout" of pest-inhibiting features. The scales can also be used to indicate areas of possible improvement by moving to the next better feature in the column; for example, "Sheltered from rain and sun" to "Protected from weather, may have winter heating".

Table 1. Progressive scales of IPM components

Level and situation	Examples	Avoid						
		En-viron-ment	Site	Object con-dition	Food waste	Lighting	Plants	Sanita-tion
[0] Outside	Totem pole, farm machine	Local climate and weather	No mod-ification	Infested	Strewn throughout and around	Ambient natural or city lighting	Nearby flowering plants and deadwood sources of insect pests	No cleaning except by natural weather-

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Level and situation	Examples	Avoid						
		Environment	Site	Object condition	Food waste	Lighting	Plants	Sanitation
								ing and wind
[1] Roof, tarp	Shrines, under eaves	Sheltered from rain and sun	Possibly elevated, roof drainage		Consolidated in open containers		Encroaching foliage cut back (reduce moisture damage)	Dry sweeping raises dusts, but may damage some insects
[2] Roof, walls, and loose-fitting doors	Temples, sheds, barns	Sheltered from some wind-blown dirt and snow	Simple foundation drainage	Cleaned	Consolidated in closed containers	Some interior lighting	Cut back encroaching trees (reduce root damage)	Clutter provides pests with shelter and interferes with inspection
[3] Basic habitation	Historic homes, churches, temples	Protected from weather, may have winter heating	Subterranean foundation drainage	Sanitary	Hauled away weekly from exterior containers	Some lights mounted on exterior	Avoid cut wildflowers or inspect for insects before bringing indoors	Household vacuum and damp mop to capture dust and insects
[4] Adapted commercial	Civic archives, private gallery	Climate controlled by HVAC system to eliminate extremes		Dis-infested	Removed daily from interior, hauled away weekly from exterior, closed containers	Mandated security lighting over doors	Restrictive policy includes inspection, treatment, or ban of high-risk vegetation (primarily local, cut wildflowers)	Clutter localized in designated work-rooms
[5] Purpose built	Provincial and national museums up to the early 1900s	Climate controlled by HVAC system to year-round human occupancy	Site-wide flood-water drainage		Exterior compactor (rodent proofed)	Low-pest-attraction lights (UV poor) on exterior	Nearby exterior: only non-flowering plants. Interior: only green-house cut flowers or	Built-in vacuum system (bag room) isolates dust and captured insects

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Level and situation	Examples	Avoid						
		En-viron-ment	Site	Object con-dition	Food waste	Lighting	Plants	Sanita-tion
		require-ments					healthy house plants in sterilized soil	
[6] Pre-servation designed	Collection pre-servation centres	Climate controlled by HVAC system to meet object pre-servation needs; low-temp-erature storage to control pests	Designed to manage 100-year cycle of extremes		Well-sealed interior garbage room (cooled) to control rodent and insect access	Attractive light draws insects from exterior walls and openings, light traps near entrance ways		HEPA vacuum portable units or built-in vacuum system with filters
[7] Ultimate		Optimal for all objects		Sterile	No food waste pro-duction		No plants that are attractive to pests	Clean room air supply

Table 2. Progressive scales of IPM components (continued)

Level	Block				Detect	Respond		Recover
	Physical barrier	Physical resistance	Object enclosure	Object shelving		Main-tenance	Suppre-ssion response	
[0]	No barriers to pests	Intrinsic to object material	Intrinsic to object construction	Objects on ground	No inspection	No main-tenance	Predators, disease, weather	No recovery, no accounting of cost
[1]	Structure may encourage bird roosting	Sheathing easily chewed or infiltrated		May sit on plinths, pallets	Annual visitation	Replace roofing, replace tarp	Residual pesticide fumigant application to entire collection	
[2]	Perforations may	Sheathing gnawed by	Cardboard boxes	Gravel, concrete slab	Unplanned obser-	Repair structural	Pesticide application targeted to	

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Level	Block				Detect	Respond		Recover
	Physical barrier	**Physical resistance**	**Object enclosure**	**Object shelving**		**Main-tenance**	**Suppre-ssion response**	
	allow rats, birds access	rodents and insects			vation during use	failures as found	specific outbreaks	
[3]	Perforations may allow mice access, window and door screen block insect entry		Chests, fabric bags, jars, dressers, cupboards, gaping cabinets	Pantry shelves, sit on wood floor, carpet	Daily familiarity, inspections associated with incidence	Repair exterior seal failures as found	Low tempera-ture, easy to obtain (control moisture risk, monitor for refrigerant leak hazard)	Thorough cleaning after infestation is treated to ease finding new outbreaks in future inspection program
[4]	Perforations may allow large insects access	Some mineral-based sheathing (joined stone brick) less prone to rodent or insect attack	Sealed wood cabinets, adapted commercial display cases, insect-resistant bags (polyethylene)	Sealed wood or metal racks elevate objects off floor	Periodic inspection of exterior and interior, incoming objects quaran-tined and visually inspected	Repair interior seal failures and interior building fabrics to support preser-vation needs including pest exclusion	Controlled atmos-phere fumigation, increases treatment capacity (assume high-pressure gas supply hazard)	Managerial analysis of pest control problems, accounting of basic capital and contract costs
[5]	Perforations may allow small insects access	Mineral-based or metal sheathing impedes rodents and insects	Some tight metal cabinets, rest are wood with loose seals	Metal racks elevate objects off sealed concrete floor	Systematic use of rodent and insect traps to map problem areas, vulnerable objects inspected	Improve exterior building fabric to support preser-vation needs	Elevated tempera-ture treatment, increases througout (controlled incre-mental thermal aging above natural rate)	Make physical improve-ments through capital planning (passive features)
[6]	Perimeter control blocks	Near seamless sheathing	All metal cabinets, gaskets,	Compact shelving	Sensitive collections visually	Replace aging component		Make procedural improve-

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Level	Block				Detect	Respond		Recover
	Physical barrier	**Physical resistance**	**Object enclosure**	**Object shelving**		**Main-tenance**	**Suppre-ssion response**	
	insects (perimeter corridor increases detection)	resists rodent or insect attack	compact shelving allows total floor cleaning		inspected annually	s before failure		ments (active features), accounting of all internal labour costs
[7]	Hermetic	Metal can	Cabinet contents in cans, vials, or boxes with hermetic seals	High-density, robotic retrieval ware-housing	All objects visually inspected annually			

Thermal control application guides

Unlike fumigation and pesticide use, thermal pest control is available to nearly everyone if they know how to achieve it. The following is a simple guide to estimate temperature and time required for effective thermal control, and to create the environment needed to kill insect pests.

Estimating time and temperature for thermal control methods

The most common question asked about applying thermal control is how long? This is discussed in sufficient detail below to help make good decisions.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

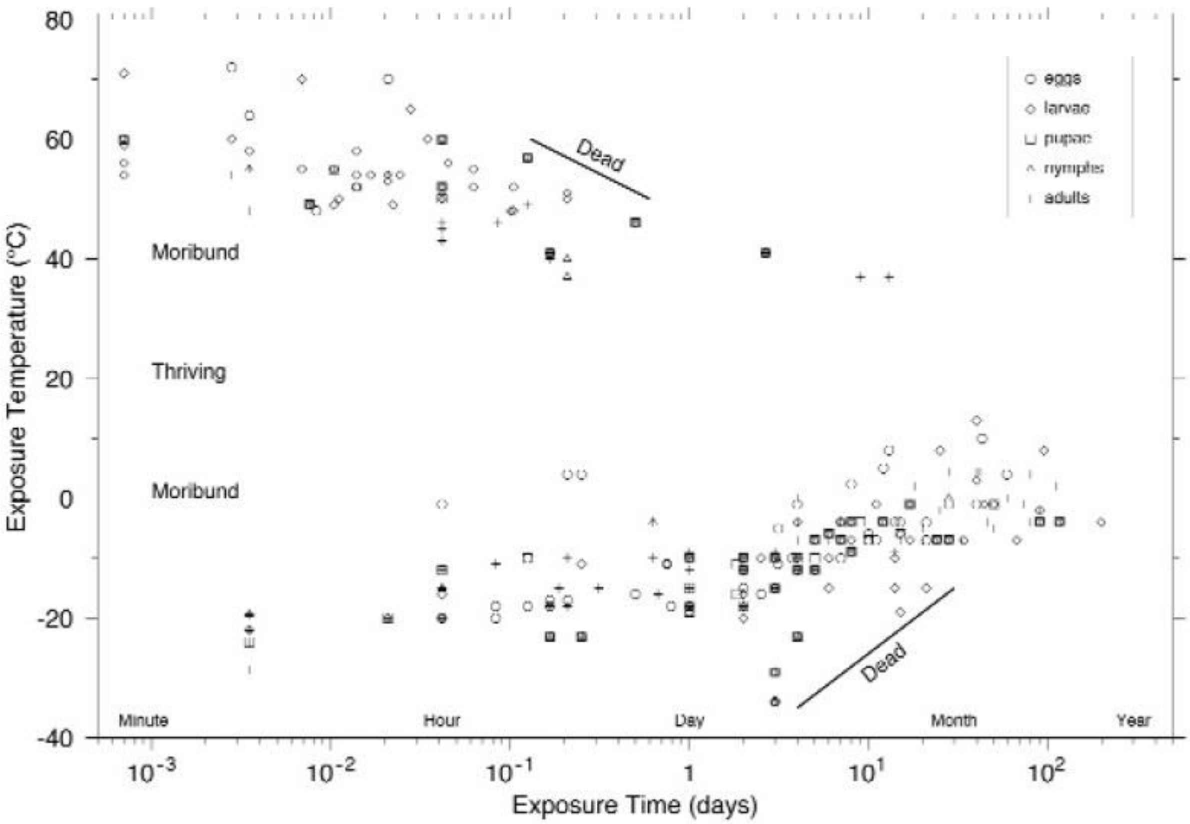

Figure 15 displays the time needed to kill insects by thermal methods. The two lines on the plot show the range of times and temperatures commonly used for treatment. Please note the logarithm scale of time is marked in days, but other familiar units lie above, centred on the individual words.

For those unfamiliar with logarithms, the first interval marked by a tick following the 10^1 (10 days) mark is 20 days, the second interval is 30 days, and so on. The value of 10^{-1} means 1/10th of a day. The term "moribund" describes the condition of the insects, but when that happens is variable by species, as shown by the wide distribution of mortality data, especially at lowered temperatures.

"Dead" status is defined by a line drawn just beyond the edge of the mortality data. This is likely a conservative estimate because the experiments were based on fixed increment inspections for any survival or recovery, rather than on looking at the subjects in real time and noting when they appeared to expire.

The low-temperature exposure method requires more time to be effective than the high-temperature protocol. Also, most low-temperature mortality occurs before and at warmer temperatures than the indicated limit line. This spread in the low-temperature data leads to various interpretations of the correct protocol. Some protocols have been specified to facilitate rapid treatment based on knowledge of the species after reviewing the data set. For such decisions, and a more detailed discussion of the data, please refer to the source paper (Strang 1992).

The boundary to the data supports a "worst case" recommendation, i.e. the material is suspected to be infested by insects, but the pest is unknown, and full control is desired. A −30°C exposure for a week or −20°C for 2 weeks will suffice. This method also presumes the objects come out of a month in warm storage, not from a cold outdoor environment in which some pest species could adapt to cold and subsequently survive such low-temperature exposure. In practice, the −30°C and −20°C exposures have usually been successful at shorter times (a few days at −30°C and a week at −20°C) because the species

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

comprising the sparser data along the boundary are less common pests in collections (consult Strang 1992 for details).

For high-temperature control, 55°C is a good maximum exposure limit. However, because the mortality of insects at this temperature is nearly instantaneous, the limiting factor is the rate of heat penetration through objects, which is displayed in Figure 16.

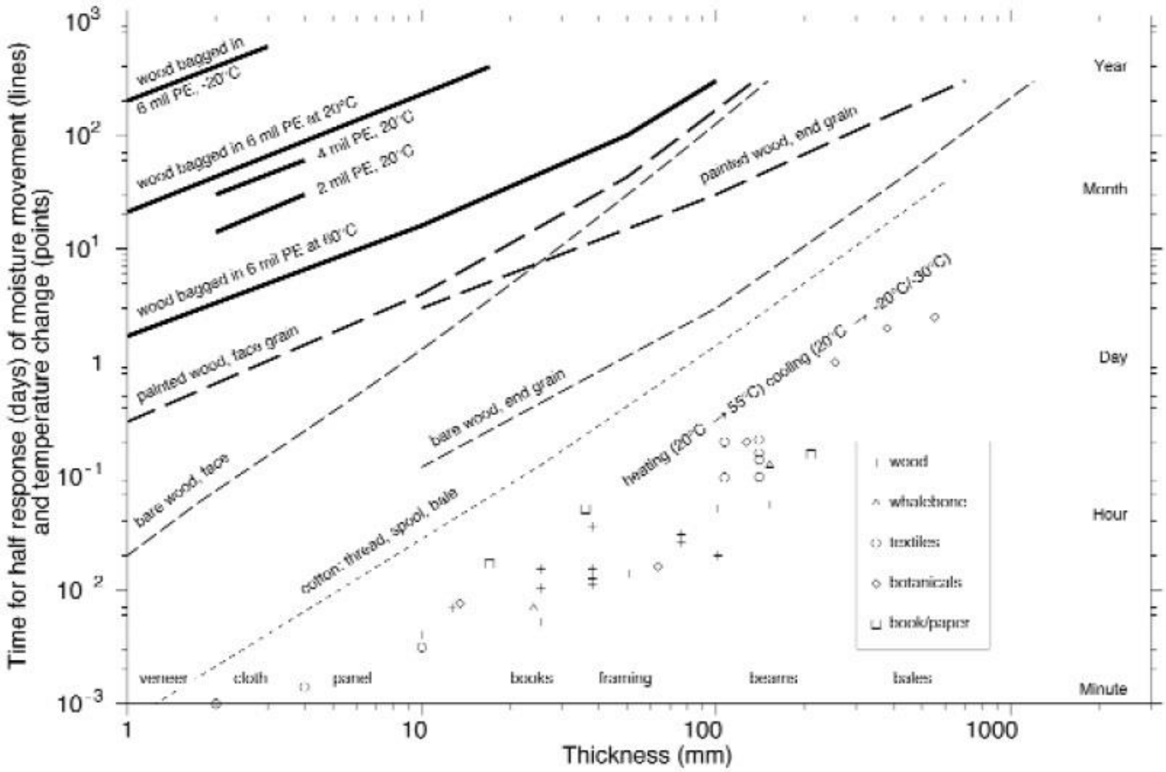

Figure 16 can be used to determine the time needed to change the temperature of an object (points), and to predict the bulk change in moisture content if it is subjected to drying or humidification (lines).

As in Figure 15, there is the use of logarithm scales. The range of values would be difficult to present otherwise. Common descriptive terms are provided to help interpret the scales.

If you imagine an object fitting inside a rectangular volume, the smallest dimension is the one referred to as thickness in Figure 16. For example, the "thickness" of a piece of wood measuring 2 in. x 4 in. x 8 in. would be 2 in. (50 mm). Finding this dimension in millimetres on the scale allows one to determine the approximate time for "half response". The half response time is how long it takes for the object to go from the start condition to half way to the end condition (for example, when going from 20 to −20/−30°C, the time to get to −5°C is the half response time). It will take roughly the same time again to go to the 3/4 point, and the same time again to go to the 7/8 point, and so on. This response time is influenced by the material's insulation properties. A key is given to show the source materials tested. You can interpret a time based on evidence from this key, or simply take the most conservative value (largest number, top of the point distribution at the specified thickness). The half response is used because it is much easier to measure than the completion point. To figure out the rough time to completion, multiply this response time by four or five. If you want to keep the treatment as short as possible, do not rely on the estimate, instead use a test block of similar material in which a thermometer probe is inserted in order to measure in real time when to terminate the treatment.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

For heat treating, the line in Figure 16 marked "wood bagged in 6 mil PE at 60°C" shows that enclosing objects in a vapour barrier before heating confers added protection against desiccation. This is a simple and common method. While the plotted lines demonstrate that paint and even "stagnant" air (technically called the "boundary layer" of air) will act as barriers to moisture loss, a simple plastic bag is the most effective and highly recommended. While there is a condensation risk inside a plastic bag during cooling after a heat treatment, letting the temperature of the container drop slowly so the dew point is not experienced inside the bag can greatly reduce this moisture hazard for sensitive objects. Wrapping the object with absorbent dunnage.

(E.g. a cotton sheet) Before bagging also provides a rapidly acting buffer to stabilize moisture content during treatment. For a full discussion of these factors and hazard mitigation, consult Strang (1995, 2001).

During low-temperature treatments, exposure to condensation on removal or to dampness from complete failure of the freezer is prevented by using vapour-resistant bagging, and leaving it on through the re-warming phase. Leaving objects in bags can also prevent reinfestation if the storage area has not yet been decontaminated. Long-term storage in vapour-resistant bags can be beneficial as long as four conditions are not allowed to occur that would promote mould growth inside the bag. These recommendations come from observing the moisture sorption isotherms for organic materials and behaviour of moisture in bagged objects. To understand the relative risk being discussed, at 65% RH, mould growth is just possible to maintain in laboratory experiments, but at this level is very unlikely to initiate spore germination. Therefore, 65% RH represents a lower limit to mould formation. Deriving from microbial research, RH is a more appropriate measure of the water available for organisms (an equivalent to water activity) than the equilibrium moisture content (EMC) of the material on which the mould may grow.

1. Do not bag objects that have equilibrated above 65% RH for long-term storage. You will simply be trapping in moisture at a level that, in time, can support mould growth.
2. Do not bag objects that have equilibrated near 65% RH and subsequently store them in warmer conditions. The rise in temperature allows moisture to leave the object and elevate the RH in the bag toward levels that support microbial life. This only holds true until the upper limit in temperature for the mould is reached. Heat treatments to control pests are too high in temperature and too short in duration to support mould growth.
3. Do not bag objects and store them resting on a hot or cold surface that induces a thermal gradient (e.g. in winter, a cold concrete floor in a heated garage). This gradient causes moisture to accumulate in the colder side of the bag. This is a "mode of failure" in shiphold transit environments and in other similar situations. The resulting dampness leads to the bagged items spoiling.
4. Do not bag objects near 65% RH and then store them for a prolonged time in air that has a significantly higher RH. The moist air will eventually permeate the bag. The timeline for this may be many years: the governing factors are quality of the barrier; whether there are pinholes in the bags; and the volume of the object providing buffering capacity in the enclosure. In the meantime, beneficial effects will be significant. If year-round humidities are expected to be above 65% RH, a mild controlled drying of objects for long-term packaged storage can be a method of preserving highly vulnerable items in these difficult environments. Including RH measuring strips in the bags to provide an early warning of problems and periodically checking them would be advisable.

All of these situations are unlikely to cause mould problems in short-term pest treatments because of a lack of time for mould response, or because of temperature limits that prevent growth (too hot or cold).

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Low-temperature control in a chest freezer or outdoors

This method is quite simple, but a few guidelines noted in the captions on the drawing need to be observed to ensure that it will work. Similar guidelines to ensure pests are killed and damage to objects is avoided should be followed when exposing objects to the cold outdoors. Outdoor exposure also requires maximizing cooling while preventing solar heat gain (e.g. use a light-coloured tarpaulin).

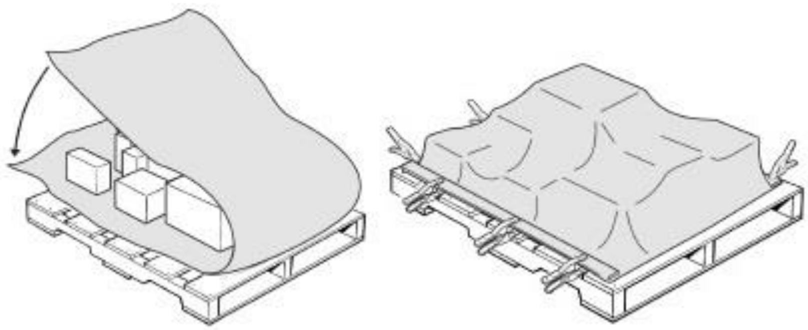

Figure 17. Outdoors: cover bagged objects with white plastic or white tarp and place on a pallet when exposing them to cold, outdoor conditions. Place objects on the shady side of the building and secure against tampering or theft. This method is only useful if the weather forecast predicts several days at −30°C or a week at a daytime high of −20°C.

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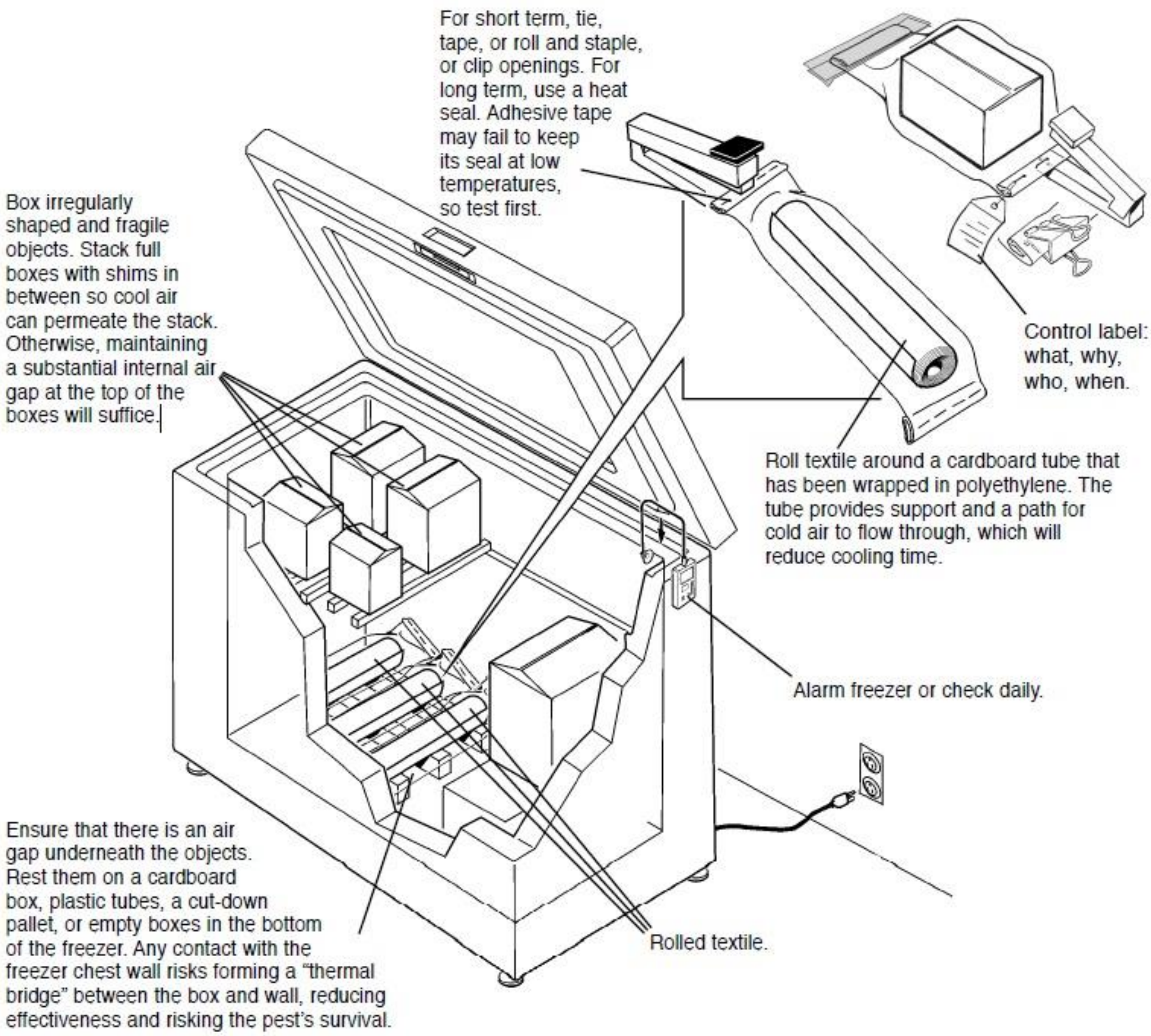

Figure 18 displays low-temperature control in a chest freezer with the following rules and items:

- Box irregularly shaped and fragile objects. Stack full boxes with shims in between so cool air can permeate the stack. Otherwise, maintaining a substantial internal air gap at the top of the boxes will suffice.
- For short term, tie, tape, or roll and staple, or clip openings. For long term, use a heat seal. Adhesive tape may fail to keep its seal at low temperatures, so test first.
- Ensure that there is an air gap underneath the objects. Rest them on a cardboard box, plastic tubes, a cut-down pallet, or empty boxes in the bottom of the freezer. Any contact with the freezer chest wall risks forming a "thermal bridge" between the box and wall, reducing effectiveness and risking the pest's survival.
- Control label: what, why, who, when
- Rolled textile.
- Roll textile around a cardboard tube that has been wrapped in polyethylene. The tube provides support and a path for cold air to flow through, which will reduce cooling time.
- Alarm freezer or check daily.

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Heat disinfestation box

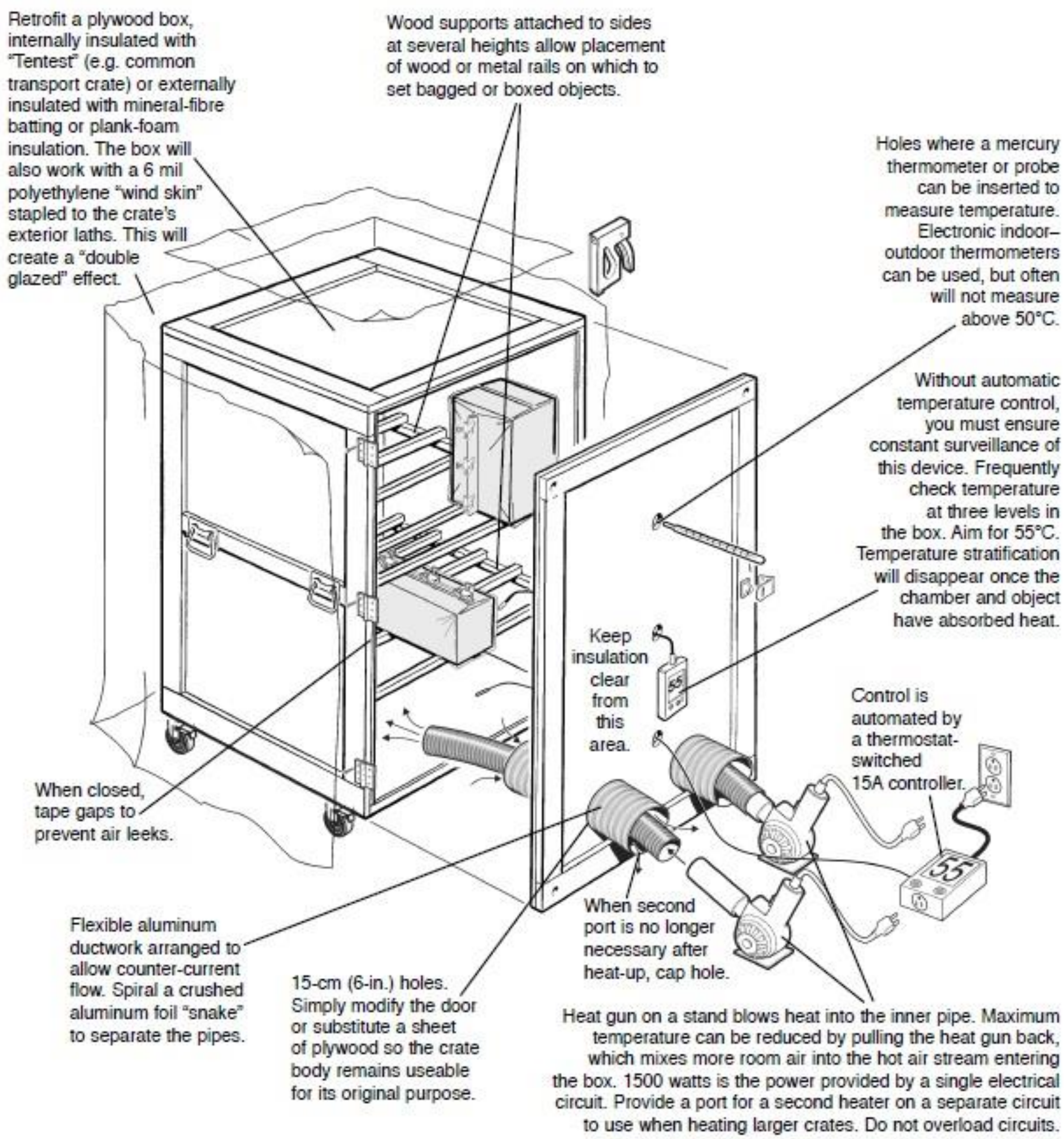

Figure 19: A wood shipping crate can be modified to make a heat disinfestation box. Instructions are as follows:

- Retrofit a plywood box, internally insulated with "Tentest" (e.g. common transport crate) or externally insulated with mineral-fibre batting or plank-foam insulation. The box will also work with a 6 mil polyethylene "wind skin" stapled to the crate's exterior laths. This will create a "double glazed" effect
- Wood supports attached to sides at several heights allow placement of wood or metal rails on which to set bagged or boxed objects.

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- Holes where a mercury thermometer or probe can be inserted to measure temperature. Electronic indoor–outdoor thermometers can be used, but often will not measure above 50°C.
- Without automatic temperature control, you must ensure constant surveillance of this device. Frequently check temperature at three levels in the box. Aim for 55°C. Temperature stratification will disappear once the chamber and object have absorbed heat.
- When closed, 15A controller. tape gaps to prevent air leeks.
- Flexible aluminum ductwork arranged to allow counter-current flow. Spiral a crushed aluminum foil "snake" to separate the pipes.
- 15-cm (6-in.) holes. Simply modify the door or substitute a sheet of plywood so the crate body remains useable for its original purpose.
- Keep insulation clear from this area.
- Control is automated by a thermostat-switched, 15A controller.
- When second port is no longer necessary after heat-up, cap hole.
- Heat gun on a stand blows heat into the inner pipe. Maximum temperature can be reduced by pulling the heat gun back, which mixes more room air into the hot air stream entering the box. 1500 watts is the power provided by a single electrical circuit. Provide a port for a second heater on a separate circuit to use when heating larger crates. Do not overload circuits.

A wood shipping crate can be modified to make a heat disinfestation box, as shown in the diagram. Heat is provided by one or two 1500-watt industrial, metal-bodied heat guns or an equivalent industrial hot air source. Do not use plastic hair dryers or household heaters because they are not designed for continuous operation at the necessary temperature. Safety is a primary issue. A Canadian Standards Association (CSA) approved heat source is placed outside the box, blowing heated air, mixed with room air, into the metal duct, which is insulated from the crate by an air gap. This technique must be supervised at all times. Pay attention to the thermometer readings especially if the box does not have automated temperature control.

Solar disinfestation plenum frame

This simple frame provides sufficient heat gain from spring to fall when used on a clear day in Canada to disinfest thick, folded textiles or other materials. The plenum design transfers heat to the shady side of the object bag, eliminating the risk of dampness forming on the shade side of the object. It also speeds up the disinfestation process. Use a thermometer to measure the temperature on the surface of the black bag containing the object, or a temperature probe or wireless thermometer inside the object bag. When the temperature appears to be rising too high (above 60°C), you can control it by turning the frame off-axis from the sun. The frame should be tied to a support to prevent the wind from toppling it.

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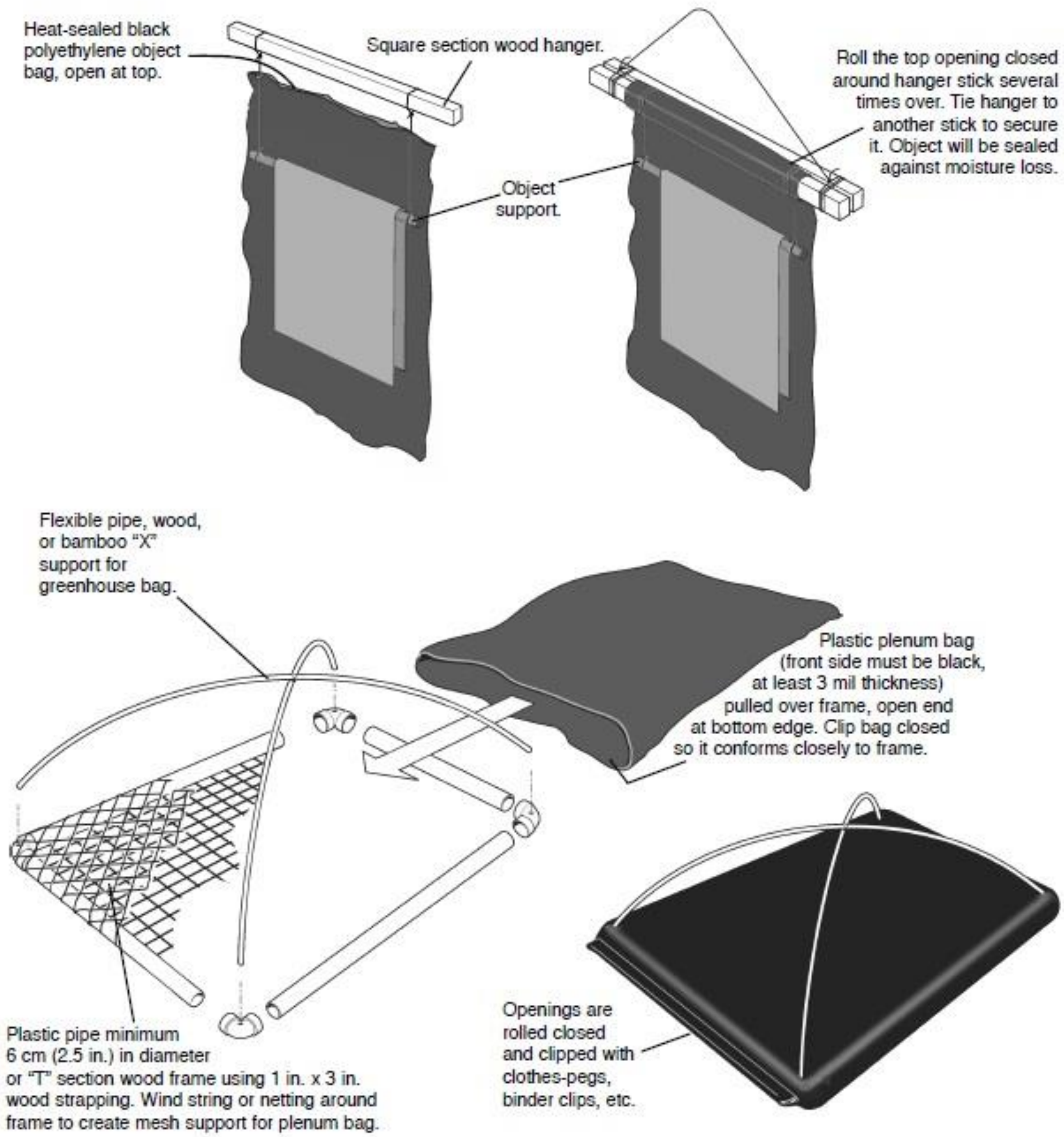

Figure 20 displays the following rules and items:

- Heat-sealed black polyethylene object bag, open at top.
- Square section wood hanger.
- Object support.
- Roll the top opening closed around hanger stick several times over. Tie hanger to another stick to secure it. Object will be sealed against moisture loss.
- Flexible pipe, wood, or bamboo "X" support for greenhouse bag.
- Plastic plenum bag (front side must be black, at least 3 mil thickness) pulled over frame, open end at bottom edge. Clip bag closed so it conforms closely to frame.
- Plastic pipe minimum 6 cm (2.5 in.) in diameter or "T" section wood frame using 1 in. x 3 in. wood strapping. Wind string or netting around frame to create mesh support for plenum bag.
- Openings are rolled closed and clipped with clothes-pegs, binder clips, etc.

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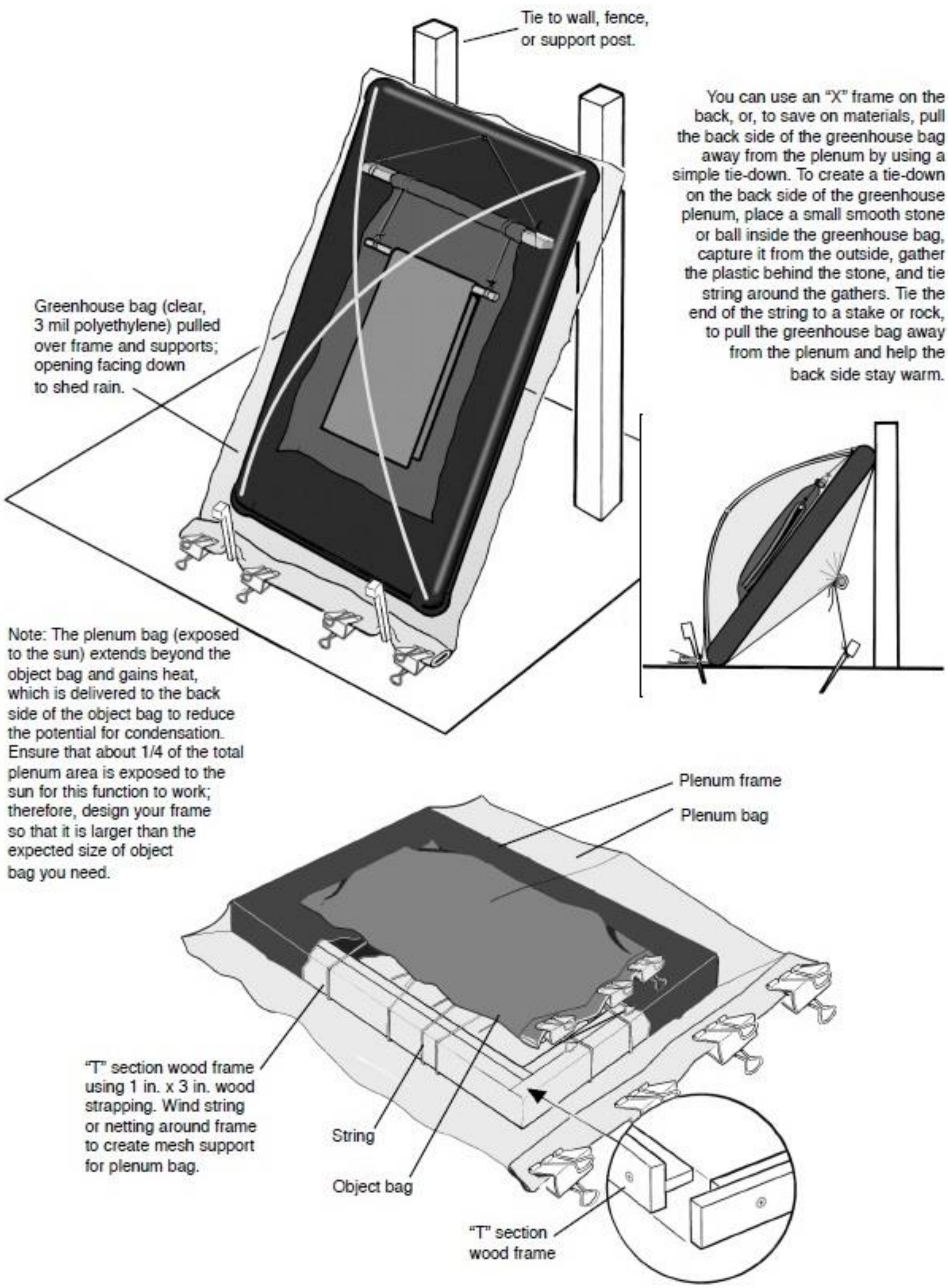

Figure 21 displays the following rules and items:

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- Greenhouse bag (clear, 3 mil polyethylene) pulled over frame and supports; opening facing down to shed rain.
- Tie to wall, fence, or support post.
- You can use an "X" frame on the back, or, to save on materials, pull the back side of the greenhouse bag away from the plenum by using a simple tie-down. To create a tie-down on the back side of the greenhouse plenum, place a small smooth stone or ball inside the greenhouse bag, capture it from the outside, gather the plastic behind the stone, and tie string around the gathers. Tie the end of the string to a stake or rock, to pull the greenhouse bag away from the plenum and help the back side stay warm.
- Note: The plenum bag (exposed to the sun) extends beyond the object bag and gains heat, which is delivered to the back side of the object bag to reduce the potential for condensation. Ensure that about 1/4 of the total plenum area is exposed to the sun for this function to work; therefore, design your frame so that it is larger than the expected size of object bag you need.
- "T" section wood frame using 1 in. x 3 in. wood strapping. Wind string or netting around frame to create mesh support for plenum bag.
- Plenum frame, Plenum bag, String, Object bag.
- "T" section wood frame

Solar disinfestation pillow

This arrangement does not require making a rigid frame. Therefore it involves a bit more careful heat sealing than does the plenum frame, but when deflated, the pillow can be stored in a much smaller space. As well, many of these pillows can be easily constructed. It is just as efficient as the plenum frame. However it is vulnerable to windy conditions; therefore, tying a pillow to stakes using a strong line is advised.

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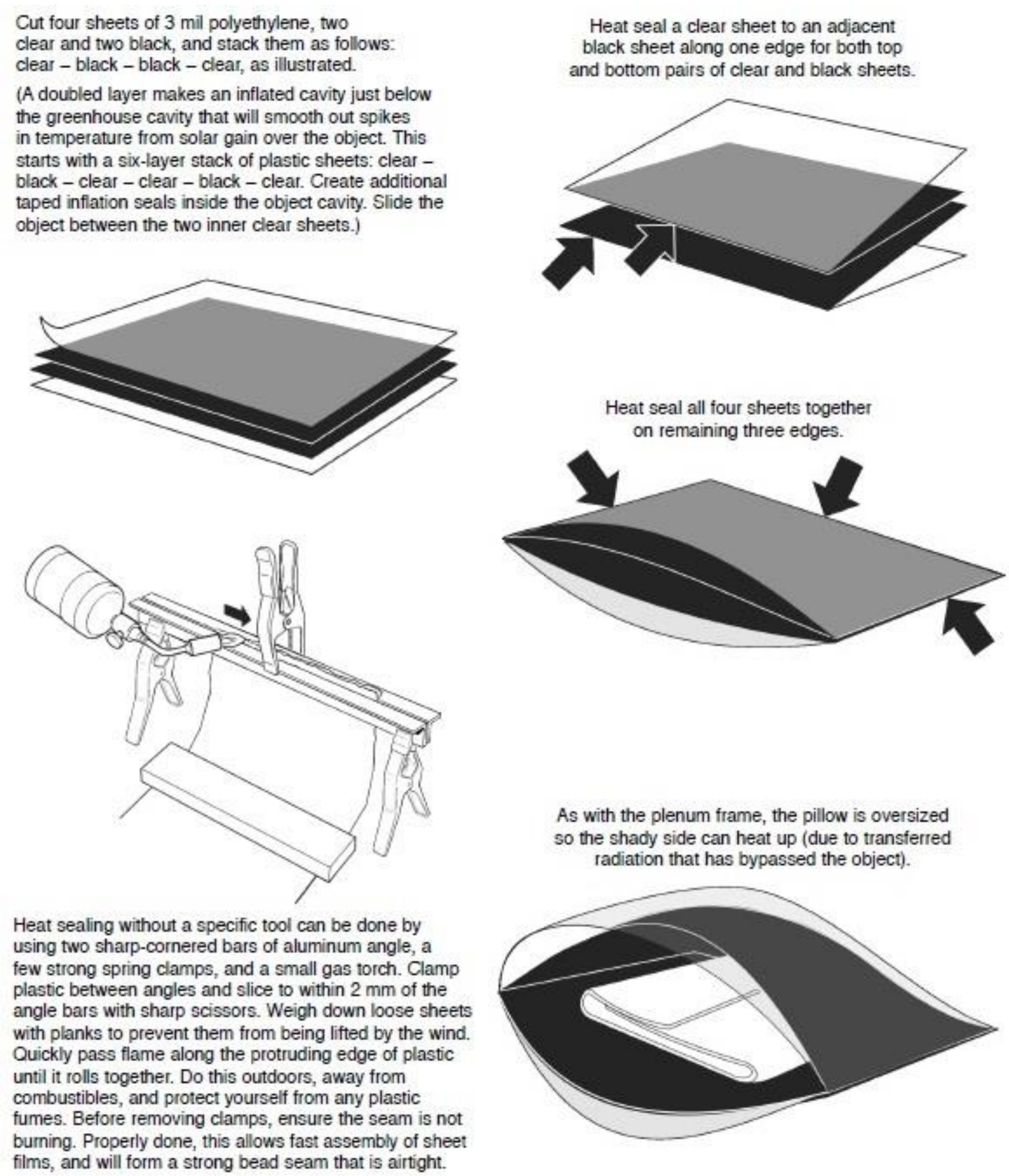

Figure 22 displays the following rules and items:

- Cut four sheets of 3 mil polyethylene, two clear and two black, and stack them as follows: clear – black – black – clear. (A doubled layer makes an inflated cavity just below the greenhouse cavity that will smooth out spikes in temperature from solar gain over the object. This starts with a six-layer stack of plastic sheets: clear – black – clear – clear – black – clear. Create additional taped inflation seals inside the object cavity. Slide the object between the two inner clear sheets.)
- Heat sealing without a specific tool can be done by using two sharp-cornered bars of aluminum angle, a few strong spring clamps, and a small gas torch. Clamp plastic between angles and slice to within 2 mm of the angle bars with sharp scissors. Weigh down loose sheets with planks to prevent

them from being lifted by the wind. Quickly pass flame along the protruding edge of plastic until it rolls together. Do this outdoors, away from combustibles, and protect yourself from any plastic fumes. Before removing clamps, ensure the seam is not burning. Properly done, this allows fast assembly of sheet films, and will form a strong bead seam that is airtight.

- Heat seal a clear sheet to an adjacent black sheet along one edge for both top and bottom pairs of clear and black sheets.
- Heat seal all four sheets together on remaining three edges.
- As with the plenum frame, the pillow is oversized so the shady side can heat up (due to transferred radiation that has bypassed the object).

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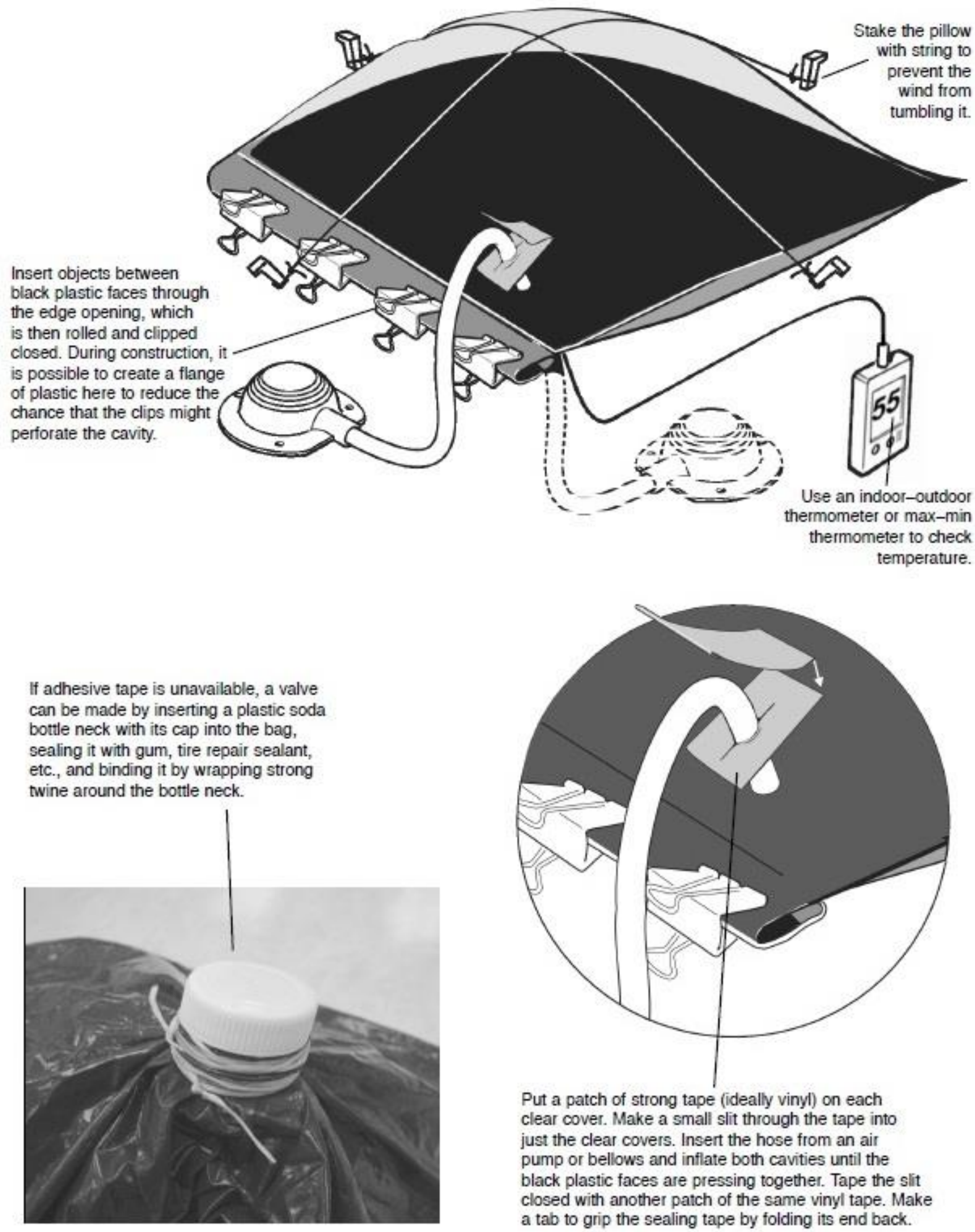

Figure 23 displays the following rules and items:

- Insert objects between black plastic faces through the edge opening, which is then rolled and clipped closed. During construction, it is possible to create a flange of plastic here to reduce the chance that the clips might perforate the cavity.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

- Stake the pillow with string to prevent the wind from tumbling it.
- Use an indoor–outdoor thermometer or max–min thermometer to check temperature.
- If adhesive tape is unavailable, a valve can be made by inserting a plastic soda bottle neck with its cap into the bag, sealing it with gum, tire repair sealant, etc., and binding it by wrapping strong twine around the bottle neck.
- Put a patch of strong tape (ideally vinyl) on each clear cover. Make a small slit through the tape into just the clear covers. Insert the hose from an air pump or bellows and inflate both cavities until the black plastic faces are pressing together. Tape the slit closed with another patch of the same vinyl tape. Make a tab to grip the sealing tape by folding its end back.

Bibliography

1. Canadian Food Inspection Agency. n.d. (accessed February 20, 2009).
2. Dawson, J. (revised by T.J.K. Strang). **Solving Museum Insect Problems: Chemical Control**. Technical Bulletin 15. Ottawa: Canadian Conservation Institute, 1992. (Pesticides and their uses.)
3. Guild, S., and M. MacDonald. **Mould Prevention and Collection Recovery: Guidelines for Heritage Collections**. Technical Bulletin 26. Ottawa: Canadian Conservation Institute, 2004.
4. Imholte, T.J. **Engineering for Food Safety and Sanitation**, 2nd edition. Medfield, MA: Technical Institute of Food Safety, 1999. (Guidelines for facility design to reduce pest hazards; contains many applications for collections buildings.)
5. Kingsley, H., D. Pinniger, A. Xavier-Rowe, and P. Winsor. **Integrated Pest Management for Collections**. London: James & James, 2001. (In-depth chapters on key aspects of IPM and case studies.)
6. Lecointre, G., and H. Le Guyader. **The Tree of Life: A Phylogenetic Classification** (translated by K. McCoy). Cambridge: The Belknap Press of Harvard University Press, 2006.
7. Maekawa, S., and K. Elert. **The Use of Oxygen-Free Environments in the Control of Museum Insect Pests**. Los Angeles: The Getty Conservation Institute, 2003. (Thorough summary of anoxic control methods for cultural property.)
8. Pinniger, D. **Pest Management in Museums, Archives and Historic Houses**. London: Archetype Publications Ltd., Reprinted 2004. 115 pp. (Concise, illustrated guide to all aspects of IPM specifically applied to cultural property; a book to begin your IPM program.)
9. Strang, T.J.K. "A Review of Published Temperatures for the Control of Pest Insects in Museums." **Collection Forum** 8, 2 (1992), pp. 41–67.
10. Strang, T.J.K. "The Effect of Thermal Methods of Pest Control on Museum Collections." pp. 334–353 in **Biodeterioration of Cultural Property 3. Proceedings of the 3rd International Conference on Biodeterioration of Cultural Property**, July 4–7, 1995 (edited by C. Aranyanak and C. Singhasiri). Bangkok, Thailand: Thammasat University Press, 1995.
11. Strang, T.J.K. **Preventing Infestations: Control Strategies and Detection Methods**. CCI Notes 3/1. Ottawa: Canadian Conservation Institute, 1996a.
12. Strang, T.J.K. **Detecting Infestations: Facility Inspection Procedure and Checklist**. CCI Notes 3/2. Ottawa: Canadian Conservation Institute, 1996b.
13. Strang, T.J.K. **Controlling Insect Pests with Low Temperature**. CCI Notes 3/3. Ottawa: Canadian Conservation Institute, 1997.
14. Strang, T.J.K. **Psocids or "Book Lice": A Warning of Dampness**. CCI Notes 3/4. Ottawa: Canadian Conservation Institute, 1998.
15. Strang, T.J.K. "Principles of Heat Disinfestation." pp. 114–129 in **Integrated Pest Management for Collections** (edited by H. Kingsley, D. Pinniger, A. Xavier-Rowe, and P. Winsor). London:

James & James, 2001. (Explains how heat disinfestation can be efficacious, rapid, and non-damaging to cultural property.)

16. Strang, T.J.K., and J.E. Dawson. **Controlling Museum Fungal Problems**. Technical Bulletin 12. Ottawa: Canadian Conservation Institute, 1991a.
17. Strang, T.J.K., and J.E. Dawson. **Controlling Vertebrate Pests in Museums**. Technical Bulletin 13. Ottawa: Canadian Conservation Institute, 1991b.
18. Strang, T.J.K., and R. Kigawa. "Levels of IPM Control: Matching Conditions to Performance and Effort." **Collection Forum** 21, 1-2 (2006), pp. 96–116. (IPM activities; categorized by applicability to situation, from outdoor objects to designed preservation facilities; a guide for approaching IPM design.)
19. Tétreault, J. **Airborne Pollutants in Museums, Galleries, and Archives: Risk Assessment, Control Strategies, and Preservation Management**. Ottawa: Canadian Conservation Institute, 2003.
20. Warren, S. "Carbon Dioxide Fumigation: Practical Case Study of a Long-Running Successful Pest Management Programme." pp. 95–101 in **Integrated Pest Management for Collections** (edited by H. Kingsley, D. Pinniger, A. Xavier-Rowe, and P. Winsor). London: James &James, 2001.

Identification guides

1. Borror, D.J., C.A. Triplehorn, and N. Johnson. **An Introduction to the Study of Insects**, 6th edition. Toronto: Harcourt Brace College Publishers, 1992. (Insect form, function, and keys for identification.)
2. Bousquet, Y. **Beetles Associated with Stored Products in Canada: An Identification Guide**. Publication #1837. Ottawa: Research Branch, Agriculture Canada, 1990. (accessed February 20, 2009).
3. Hedges, S.A., and M.S. Lacey. **A Field Guide for the Management of Structure-Infesting Beetles**. Cleveland, OH: G.I.E Inc. Publishers, 2002.
4. Mallis, A., D. Moreland, and S.A. Hedges (editors). **The Mallis Handbook of Pest Control**, 9th edition. Cleveland, OH: Mallis Handbook & Technical Training Company, 2004. (The standard reference for the pest control industry.)
5. Meaney, P. **Carpet Beetles, Textile Moths and Related Insect Pests**. The Harvard Library – Handbook One. Leicester, UK: Harvard Pest Consultancy, 2004.
6. Meehan, A.P. **Rats and Mice: Their Biology and Control. East Grinstead**, UK: Rentokil Limited, 1984.

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Glossary

French terms are in parentheses.

Arthropods (Arthropodes)

Animals with multi-part bodies, exoskeletons; includes spiders and insects.

Anoxia (noxie)

A state without oxygen.

Bacteria (Bactéries)

Self-dividing single-cell organisms that digest matter. Some can infect other living organisms.

Bait station (Point d'appât)

A secure container designed to deliver poison bait to pests (commonly rodents) while protecting other animals and humans from coming into contact with the bait.

Controlled atmosphere fumigation (Fumigation sous atmosphère contrôlée)

Altering standard atmospheric gas ratios to kill a living organism by suffocation, desiccation, and disrupted metabolism.

Disinfestation (Désinfestation)

The act of killing or removing an infestation.

EMC (Degré d'humidité d'équilibre)

Equilibrium moisture content; percentage of object mass that is water after waiting until no mass change is measurable at a specified humidity and temperature.

Enclosure (Mise sous enceinte)

The act of enclosing to prevent pests entering or escaping; the physical means of enclosing, by using bags, boxes, jars, vials, or other containers, including buildings; the provision of a degree of separation from the external environment.

Fumigation (Fumigation)

Use of a toxic gas or vapour to kill an organism.

Fungi (Champignons)

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Multicellular organisms that form colonies, characterized by hyphae and spore-forming bodies (e.g. mushrooms, mould).

Geotextile (Géotextile)

Engineered fabric or film material to control soil movement or water in soil.

Hypercarbia (Hypercarbie)

Elevated concentrations of carbon dioxide gas (greater than 0.03% in Earth atmosphere).

Insects (Insectes)

Animals with six legs, an exoskeleton, and three distinct body parts (head, thorax, abdomen).

Integrated pest management (IPM) (Lutte intégrée)

A methodology for combining activities to suppress pest damage through knowledge of pest biology, environmental factors, and response technologies, while being compatible with preservation of cultural objects.

Integument (Tégument)

Outer shell or exoskeleton of arthropods.

Microorganisms (Microorganismes)

"Tiny rascals that rule planet Earth."

Mould (Moisissures)

Mono- and multicellular fungi characterized by forming thin mats or distributed colonies over surfaces.

Oxygen scavenger (Sorbant)

A chemical substance that is added to an oxygen barrier container in order to remove unwanted oxygen.

Pest (Organisme nuisible, parasite)

Something living, but unwanted.

Pesticide (Pesticide)

A solid, liquid, or gaseous chemical intended to eliminate a living organism.

Quarantine (Quarantaine)

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A process of isolation, determination of hazard, and treatment.

Registered pesticide (Pesticide homologué)

A compound legal to use as a pesticide in specific jurisdictions, which has known formulation, human toxicity, and efficacy.

RH (HR)

Relative humidity; portion of water vapour present divided by the upper limit of water vapour possible at any one temperature.

Rodent (Rongeur)

Vertebrate, characterized by permanently growing incisor teeth, e.g. mice, rats.

Semiochemicals (Substances sémiochimiques)

Chemicals that alter an organism's behaviour.

Structural pests (Ravageurs des structures)

Pests of buildings whose activities affect building strength.

Symbiosis (Symbiose)

Beneficial/cooperative living arrangement between organisms, e.g. non-pathological association of microorganisms and insects for digesting food.

Systematics (Systématique)

The science of classifying organisms into related groups.

Thermal control (Lutte thermique)

Use of low or high temperatures to eliminate a living organism.

Viruses (Virus)

Infectious particles containing genetic material that commandeers living cells for their own reproduction.

Zoonoses (Zoonoses)

Diseases of non-human origin that cross over to humans in close contact with infected animals or their wastes (e.g. H5N1 avian influenza)

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Thanks to the Centro Nacional de Conservación y Restauración in Chile, the Canadian Conservation Institute's web resource Agents of deterioration, translated into Spanish by ICCROM, is now available free of charge. Intended for curators and conservators, the resource identifies 10 primary threats specific to heritage environments.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Pollutants

Jean Tétreault

Pollutants are grouped into a range of compounds that can have chemical reactions with any component of an object. Pollutants can be gases, aerosols, liquids or solids of either anthropogenic or natural origin, and they are substances that are known to have adverse effects (negative consequences) on objects. Deposits of solid particles are considered pollutants, and while they may not necessarily cause damage, they are recognized as altering the aesthetic aspects of the objects. In some cases, fine particles deposited on an object's surface can be strongly bonded.

In a museum, there are three modes of action for pollutants to reach objects and cause deterioration. In the first mode, the pollutants are airborne; in the second, the pollutants are transferred between two materials at points of contact; as for the third, it is intrinsic, in that the pollutant already exists, as part of the materials composing the object, or is formed during chemical reactions on or within it. The latter is called also called a **secondary** pollutant. Each of these modes of action will be discussed further below. Table 1 shows some common pollutants, their nature and their effects.

Table 1. Effects of pollutants on objects.

Pollutants	Nature	Effects
Airborne pollutants	Atmospheric sources: ozone, hydrogen sulfide, carbonyl sulfide, sulfur dioxide, nitrogen dioxide, and particles (e.g. soot, salts). From emissive products, objects and people: sulfur-based gases, organic acids (e.g. carboxylic acids), particles (e.g. lints, danders).	Acidification of papers, corrosion of metals, discoloration of colorants, efflorescence of calcium-based objects with RH (e.g. seashells), loss of strength for textiles. Dust: disfiguration of objects; attractant for pests, scratching of soft surfaces by friction.
Pollutants transferred by contact	Plasticizer from flexible PVC (polyvinyl chloride), sulfur compounds from natural rubber, staining materials from wood (especially knots), viscous compounds from old polyurethane foams, paper clips on papers, adhesives on objects from previous presentation, oily materials from leather, acids from some mineral specimens, fatty acids from people or from greasy objects such as skin/leather. Impregnation of salts during burial or immersion in seawater. Impregnation of residue of cleaning agents. Impregnation of salt from brick or stone floors or foundation.	Discoloration or corrosion of surface of the object in contact with harmful material from products or objects.
Intrinsic pollutants	Composite objects having compounds harmful for the other parts of the object, such as alum or iron gall ink in papers, 'original' adhesive tape on papers, corrosion of copper in contact with leather (e.g. tanned leather object having copper parts), composite objects made of sulfur- based compounds and metals.	Deterioration of the objects: acidification, discoloration or stain on objects. Secondary pollutant may speed up the degradation processes caused by oxygen, water vapour or other pollutants.

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Pollutants	Nature	Effects
	Secondary pollutants such as acetic acid and nitrogen oxide compounds from the hydrolysis of cellulose acetate and cellulose nitrate respectively.	

Airborne pollutants

Airborne pollutants are either of anthropogenic or natural origin, and are carried by the air. Traditionally, they are mostly associated with industrial and urban activities. Within buildings, some pollutants can be generated by construction products. Staff and visitors are also a potential source of indoor airborne pollutants.

It is uncertain how many airborne compounds in any environment are actually harmful to objects, but it is possible to focus on those that are known to be the most harmful. Seven compounds have been identified as key airborne pollutants:

- acetic acid
- hydrogen sulfide
- nitrogen dioxide
- ozone
- sulfur dioxide
- fine particles
- water vapour

These key pollutants are common, and their reactivity is equal to or greater than the other pollutants of the same chemical group. Thus, strategies to control the seven key pollutants will generally also control the other airborne pollutants.

Acetic acid

This carboxylic acid (CH3COOH) is mainly generated indoors when inappropriate products are used, and may cause problems in airtight enclosures. Typically, an enclosure constructed using poorly chosen wood and paints will cause problems. Lead is the most sensitive material to acetic acid (Figure 1 and Vignette 1) and it is often found corroded where acidic woods or inadequate paints are chosen to build display or storage cabinets.

Hydrogen sulfide

Hydrogen sulfide (H_2S), a reduced-sulfur gas with a characteristic "rotten egg" odour, is a key pollutant due to its great ability to tarnish silver (Figure 2) and copper within a very short time, even outside of urban areas. The darkening of lead white pigment in paintings is also caused by the presence of reduced-sulfur gases. The main anthropogenic sources of hydrogen sulfide are the pulp-and-paper and petroleum industries. Outside the urban environment, hydrogen sulfide is emitted by oceans, volcanic and geothermal activities, marshes, and vegetation. Inside buildings, staff and visitors are often the major source of hydrogen sulfide.

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Nitrogen dioxide

The most common compound of the nitrogen oxide group (NOX), nitrogen dioxide (NO2) is responsible for the reddish brown colour above cities, especially during periods of photochemical smog. NO2 is formed rapidly in the atmosphere by the action of ozone on nitric oxide (NO), which is the major nitrogen oxide emitted by combustion in vehicles (about 50% of emissions), power plants, and industrial activities. In the atmosphere, a fraction of nitrogen dioxide can be further oxidized to its acid form: nitric acid (HNO3). Both nitric acid and nitrogen dioxide cause artists' colorants to fade and can contribute to the degradation of paper and vegetable-tanned leather. It is also believed that the nitrogen oxide absorbed by objects becomes oxidized to nitric acid, the latter being responsible for most of the ensuing deterioration.

Ozone

Ozone (O_3) is a strong oxidant that is normally present in the stratosphere and protects us against intense, harmful ultraviolet radiation. At ground level, it is formed during photochemical smog. Photochemical smog is the result of multiple chemical reactions between nitrogen oxides and hydrocarbons, and their oxygenated derivatives in the presence of sunlight. In Canada, the Windsor–Quebec City corridor has the highest levels of ozone. This is due to the high population density and the industrialization of the corridor, and to the dominant southwest winds that carry ozone precursors, especially from the area immediately south of the Great Lakes. The transport of ozone precursors in the atmosphere results in high levels of ozone in remote areas where there are no major human activities. Inside buildings, the main sources of ozone are electrostatic precipitators in the heating, ventilation, and air-conditioning (HVAC) system, electronic air cleaners (ozone generators), and photocopiers. Ozone has the capacity to attack materials by breaking apart any double bonds between carbon atoms. The degradation of vulcanized natural rubbers under stress and the fading of artists' colorants are the most studied phenomena.

Sulfur dioxide

In the United States and in Europe, power plants based on coal and oil combustion are the major sources of sulfur dioxide (SO_2), followed by industrial processes and transportation. Only small quantities of sulfur dioxide come from gasoline-fuelled motor vehicle exhaust. In Canada, industrial activity, specifically metal smelting, is the main source of sulfur dioxide. Inside enclosures materials such as proteinaceous substances, sulfur-vulcanized rubbers, oxidizing sulfides in geological specimens, and some dyes are sources of sulfur compounds. sulfur dioxide causes corrosion of copper, fading of some artists' colorants and weakening of vegetable-tanned leathers (Figure 3). Both sulfur dioxide and nitrogen dioxide have been largely associated with the acidification of papers where acid rain and urban pollution are an acute problem.

Fine particles

It is common to characterize particulate matter (dust) in terms of aerodynamic diameter, which is defined as the diameter of a sphere with a unit density having an aerodynamic behaviour equivalent to that of the particle in question. The aerodynamic diameter is important, because it determines its behaviour and control. For the control of pollutants, the fine particle ($PM_{2.5}$: suspended particle matter having an aerodynamic diameter equal to or less than 2.5 µm) and the coarse particle (PM_{10}: aerodynamic diameter between 2.5 and 10 µm) are commonly used as indicators. Due to the small size of $PM_{2.5}$, it is the most challenging particle size to control. Sulphate and nitrate compounds, organic carbon, crustal materials, and salts are the major harmful outdoor compounds forming fine particulate matter ($PM_{2.5}$). Any attempt to control the level of $PM_{2.5}$ must consider **a priori** the control of levels of PM_{10} and some super coarse particles (>10 µm), which still contain some potentially reactive compounds, such as combustion residues, human danders, and microbiological specimens. Fine particles are particularly damaging, because they discolour or soil surfaces. Soiling changes the visual appearance of objects. The more fragile, porous, or altered the surfaces, the more difficult they are to clean. Any control strategy designed to maintain low levels of particles is beneficial to objects, since cleaning fragile or porous objects can be difficult and time consuming. Object cleaning is a delicate process that requires trained conservators. The ivory sculpture (Figure 4) is a good example of an object that is challenging to clean. The deposit of hygroscopic, oily, or metallic particles on a surface can initiate or accelerate deterioration, as well as the formation of harmful compounds such as acids. With the exception of particles generated by cooking activities in a museum's cafeteria or the burning of combustibles (candles and lamps), most indoor-generated particles are composed of soil, and fibres from carpet and cloth. Fibres are not generally considered to have direct adverse effects on collections, except for of magnetic media such as audio and video tapes, where abrasive dusts are an issue during handling and playing. Dust accumulation can also provide an attractive foraging place for insects, and can initiate mould. From a wider viewpoint, another adverse consequence is the impact of the perception by visitors, including potential donors, that there is a basic lack of care for the collection.

Water vapour

Water (H_2O) is included as a key airborne pollutant, even though there are well-established guidelines for relative humidity levels for museums in order to prevent physical deterioration caused by incorrect levels (too dry or too humid), or by excessive fluctuations (see section on Incorrect relative humidity). The action of water vapour as a pollutant relates to both physical and chemical damage. Through hydrolysis, water vapour can directly damage cellulose-based materials such as book and paper artworks, which are usually an important part of collections. Materials that are sensitive to the hydrolysis action of water vapour include cellulose acetate and cellulose nitrate (Figure 8 and Figure 9), especially in the form of thin sheets or rolled films, papers, and magnetic tapes. Water vapour also greatly influences the deterioration processes caused by other pollutants.

Oxygen

Oxygen (O_2) is naturally part of the atmosphere. Without necessarily being the initiator, oxygen is involved in many deterioration processes of organic materials, such as some colorants, polymers, cellulose-based objects, and skins. The deterioration is caused by the oxidation of a compound after being photo-excited by UV or visible radiation. The resulting oxidation leads to physical changes, such as brittleness and cracking, as well as chemical changes, such as yellowing and fading. In the presence of moisture, metals such as iron will rust. Up to now, low oxygen or anaerobic environments have been mainly used for disinfestation and for long-term storage of individual objects in airtight bags. There are few case studies of the use of low-oxygen environments for large enclosures. This is partly due to problems related to airtightness, maintenance costs, and access. Because of the limited use of low-oxygen environments and the unnecessary need to include oxygen in basic monitoring campaigns, oxygen has not been classified as a key pollutant.

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Mosaic of photographs showing typical damage caused by pollutants

Figure 1. A lead paten or weight severely corroding, due to chipboard bottom of display case (photo courtesy of Christoph Waller).

Figure 2. Silver-plated copper key ring had slowly tarnished due to the presence of reduced sulfur compounds in the room.

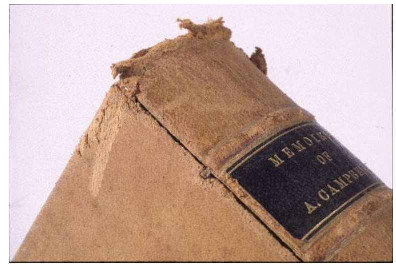

Figure 3. Book covered with vegetable tanned leather shows significant deterioration known as red rot caused by sulfur dioxide.

Figure 4. Inuit ivory sculpture with soot encrusted in the cracks.

Figure 5. Rubber tube staining a booklet after about 10 years of contact.

Figure 6. Efflorescence on shells. The shell on the right has been exposed to a high concentration of acetic acid vapour.

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Figure 7. Copper in contact with a greasy leather forming a waxy green copper corrosion compound: copper stearate; this is a example of an intrinsic pollutant.

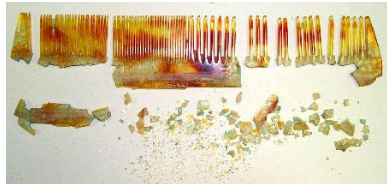

Figure 8. Cellulose nitrate comb made in the 1960's, highly brittle due to hydrolysis.

Figure 9. Cellulose acetate negative sheet at an advanced stage of degradation, also due to hydrolysis. The film base is yellow and very brittle.

Control strategies for airborne pollutants

Guidelines on levels of airborne pollutants

Airborne pollutants around collections are undesirable. Although it can be very expensive both in money and time to maintain a very low level of pollutants, the concept of degree of preservation can help in determining whether the preservation of the collection against pollutants is suitable in terms of the mandate and resources of the museum. This is based mainly on the concept of dose (the concentration of the pollutant multiplied by the duration of exposure) at which the first signs of deterioration caused by a pollutant are measurable in a material. In the jargon of risk management, this dose is called the "lowest observed adverse effect dose" (LOAED). In accordance with the principle of reciprocity, for a given dose of a pollutant on an object, it is possible to calculate the exposure time required before signs of damage appear. For example, basic fuchsin (a green dye) first begins to turn a lighter colour at a dose of 10 micrograms of sulfur dioxide per cubic metre year (10 $\mu g\ m^{-3}$ yr). Therefore, if we are willing to accept a slight color change after 10 years, the average concentration of sulfur dioxide must be reduced to less than 1 $\mu g\ m^{-3}$ (10 $\mu g\ m^{-3}$yr / 10 years).

Table 2 shows the maximum allowable concentration for each key airborne pollutant to provide minimal risk to most materials for the indicated exposure periods. These maximum levels of pollutants have been grouped in three degrees, or targets, of preservation: 1, 10, and 100 years. The 100-year target provides the greatest preservation, and means that most objects should not show adverse effects for 100 years when exposed to the maximum level of pollutants allowed in the respective column. For most objects, it is probably unrealistic and unreliable to specify pollutant concentrations in the room lower than those allowed by the preservation target for 100 years. Intermediate targets, such as 50 or 80 years, can also be adopted. It is important to stress that Table 2 gives degree of preservation based on medium sensitivity

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

objects that include the majority of the collection. High risk materials, shown in Table 3 are excluded because it can be too expensive to provide a global control strategy intended to preserve all objects, including the high risk ones. It is much more cost effective to provide a higher level of preservation to high risk objects, and a global approach to the overall collection. It is very important to identify the highly sensitive objects in the collection so that extra attention can be focussed on them.

Table 2. Guidelines on levels of airborne pollutants (based on Tétreault 2003)

Key airborne pollutants	Maximum average concentration for indicated preservation targets, μg m^{-3} (ppb)[1]			Reference average concentration range, μg m^{-3}	
	1 yr	10 yrs	100 yrs	Clean low troposphere	Urban area
Acetic acid	1000 (400)	100	100	0.3–5	0.5–20[2]
Hydrogen sulfide	1 (0.71)	0.1	0.01	0.01–1	0.02–1
Nitrogen dioxide	10 (5.2)	1	0.1	0.2–20	3–200
Ozone	10 (5.0)	1	0.1	2–200	20–300
Sulfur dioxide	10 (3.8)	1	0.1	0.1–30	6–100
Fine particles ($PM_{2.5}$)	10	1	0.1	1–30	1–100
Water vapour	keep below 60% RH[3]			N/A	

1. Preservation target is the length of time (in years) for which the objects can be exposed to the indicated level of pollutants with minimal risk of deterioration. These targets are based on the LOAED of most objects (exclude high risk objects; consult Table 3) and assume that average RH is kept between 50 and 60%, temperature ranges between 20 and 30°C, and the collection is kept clean (if not, the maximum levels of key airborne pollutants for each class of targets may need to be readjusted). These values are not applicable to high risk materials – **ppb** means parts per billion.
2. Acetic acid levels can be emitted to levels as high as 10,000 μg m^{-3} in enclosures made with inappropriate materials, such as fresh acid-cured silicone.
3. For permanent collections where the RH has not been kept between 50 and 60%, maintain the historical conditions.

Table 3. List of high risk objects to their respective airborne pollutants

Objects and potential damage[1]	Most harmful airborne pollutants and their sources
Sensitivity colorants such alizarin crimson, basic fuchsin, curcumin and pararosaniline base: they tend to fade.	Typically outdoor pollutants such as nitrogen dioxide, Sulfur dioxide and ozone.
Lead: in enclosure, in presence of carboxylic acid-emissive products, lead tends to corrode by forming a white powder on its surface.	Mainly acetic and formic acid from wood, especially oak and cedar and/or in presence of oil based or alkyd paints in enclosure.
Natural rubber (vulcanized or not): especially under stress, the rubber tends to crack and become brittle.	Ozone from the low atmosphere.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Objects and potential damage[1]	Most harmful airborne pollutants and their sources
Synthetic rubbers are sensitive, but to a lesser extent.	
Silver: well known to tarnish easily in ambient conditions in a year. Frequent cleaning may cause loss of information and can be a serious issue if the layer of silver is thin.	Reduced sulfur gases such as Hydrogen sulfide, carbon disulphide and carbonyl sulphide from natural and anthropogenic sources. Inside museums, visitors can be the main source of Hydrogen sulfide. Some products may contain sulfur-based compounds.
Magnetic tapes (audio, video, data): presence of dust will contaminate equipment and lead to read errors for digital tapes or signal losses known as dropout for analog tapes, and scratching of the tape surfaces. Grooved recordings (78's, 45's, 33's and cylinders): because contact with a stylus is required, the presence of dust will lead to damage if these media are played without proper cleaning.	Particles from outdoors and from indoors (danders and lints from staff and visitors, and human activities such as renovation and cooking).
Objects that are difficult to clean. This includes objects with powdery pigments or surfaces such as some painted ethnographic objects or feathers, some butterfly wings; physically fragile objects such as insect collections and filamentous mineral specimens; objects in which fine particles could become lodged in microcracks or interstices (e.g. ivories or painted objects with cracks); objects with sticky surfaces such as certain deteriorated plastics and some polyethylene glycol treated wooden waterlogged objects; objects that cannot be easily cleaned by vacuum cleaning, immersion baths, or poultices; and objects with numerous small components that would be difficult and time-consuming to clean well.	Fine particles from outside, mainly caused by the combustion associated with urban transportation.
Moisture-sensitive objects (sensitive to hydrolysis) such as cellulose acetate and cellulose nitrate, colour photographic prints, photographic gelatin, magnetic recording tapes, many types of papers, natural varnishes, flexible (plasticized) PVC. Damages depend of the nature of the material, but can include discoloration, acidification, tensile strength loss and deformation.	Water vapour from visitors, water-based paints, and adhesives, wet cleaning activities and outdoor environment.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Objects and potential damage[1]	Most harmful airborne pollutants and their sources
Objects containing water soluble salts that are known to react with acetic and formic acids, including ceramics, seashells, minerals. They are prone to develop long filament crystals or snowy flakes (efflorescence).	Water vapour, acetic acid, formic acid and objects with internal salt or acetate compounds.
1. Consider control of strategies associated with a higher degree of preservation or consult Tétreault (2003).	

The maximum concentration of key airborne pollutants allowed in Table 2 for the preservation targets of 1 and 10 years can be considered effective and achievable for preservation purposes. Many objects will not show the first signs of deterioration until after the designated exposure period. In the rooms of most historic buildings, a target of around 10 years is, in fact, the best that can be achieved. However, achieving pollutant levels with a low preservation target in a room can contribute to a better degree of preservation in an enclosure if there are no significant emissive sources of pollutants inside.

The ease with which a specific degree of preservation in a room is achieved depends on the LOAED value of the pollutant to the majority of the collection. This is exactly the same value as given in the one-year target in Table 2 (for NO_2; $10\ \mu g\ m^{-3} \times 1\ yr = 10\ \mu g\ m^{-3}\ yr^{-1}$). The higher the LOAED value and the lower the outdoor concentration, the easier it is to achieve a high degree of preservation. If there is an internal source of a pollutant, such as a high number of visitors emitting hydrogen sulfide, a high degree of preservation can be more difficult to achieve. It all depends upon the actual facilities, and the resources available for improving air quality.

Systematic approach

Control strategies are coordinated measures intended to reduce one or more airborne pollutants to a certain level, thereby limiting the risk or the rate of deterioration of objects exposed to them. These measures can be derived from specifications, which are accurate descriptions of technical requirements for the performance of building features, portable fittings, and procedures. Table 4 summarizes the various control strategies to prevent adverse effects of airborne pollutants. It shows the possibilities for control at different stages. Avoid, block, dilute, and filter/sorb are strategies to reduce the levels of pollutants in the ambient air. Reduce reaction is a strategy for minimizing the adverse effects of pollutants on objects. This strategy consists, firstly, in the reduction of environmental factors such as radiations and compounds that are involved in the reaction without being the main pollutant. Secondly, the strategy consists in the neutralisation of the sorbed pollutants in the objects. The mass deacidification of books is based on this strategy. Reducing exposure is a strategy for controlling deterioration by limiting the exposure of objects to the harmful environment. Whenever feasible, avoiding sources of pollutants is the best option. However, there are unfortunately few options available to avoid outdoor pollutants, the most realistic being the blocking strategy. For indoor-generated pollutants, the avoid strategy (i.e. avoiding exposure by selecting safe products) is the most efficient choice for enclosures. If this cannot be done, the block, the dilution or the filter/sorb strategies will provide a partial reduction in pollutants. It is important to note that control strategies do not have to be uniformly applied throughout the museum. They can be tailored to the value and need for preservation of the objects, as well as to individual rooms and enclosures.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Control strategies for the control of airborne pollutants (Tétreault 2003)

AVOID outdoor sources

- Select proper locations for new buildings based on surrounding sources of airborne pollutants such as pollution-emitting industries and dominant winds.
- Minimize the generation of pollutants, e.g. pave the parking lot, limit traffic in the immediate vicinity of the building.

AVOID sources in rooms/building

- Minimize dust- and gas-generating activities close to the collection or in the same ventilation zone.
- Limit the number of visitors per room, depending on the ventilation capacity.
- Carefully select and use products based on their chemical components.

AVOID sources in enclosures

- Carefully select and use products based on their chemical components.

BLOCK infiltration of pollutants in rooms/building

- Improve airtightness of the building membrane, or of some rooms; add vestibules for the main doors and open windows wisely.
- Select proper location for the air intake of the HVAC system system, provide different positive pressure zones with a minimum air intake ratio. Insert efficient gas and particle filters. Change filters periodically as recommended by the manufacturer, or based on the results of assessment done by an air quality firm.

BLOCK infiltration of pollutants in enclosures

- Use airtight enclosures or use air-filtered positive pressure systems. Change filters periodically.
- Wrap objects with sorbent tissues, such as acid-free tissues or cotton fabrics.

BLOCK emission of pollutants from products in rooms/enclosures

- Apply a barrier film on the surface of emissive wood products

BLOCK transfer (deposition or sorption) of pollutants on objects

- Apply a barrier film on the surface of objects (limited option).

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

DILUTE, FILTER, or SORB pollutants in rooms/building

- Consider wise distribution of collections in the different air quality zones of the building (including the possibility of using an enclosure).
- Increase the distance between the source and objects.
- Use local exhaust for the most polluting activities (cooking, workshop, chemical storage).
- Use portable fans to push the air out of the rooms/building (short-term high emission such as fresh painted walls or floors).
- Filter the recirculating air of the HVAC system system or use a portable filter unit. Change filters periodically.
- Remove dust accumulation in the building and on portable fitting surfaces periodically. Minimize resuspension of dust.

DILUTE or SORB pollutants in enclosures

- Consider stack pressure design of the enclosure if the environment of the room is well controlled, or use air-filtered positive pressure systems.
- Dilute (flush) air with a non-reactive gas such as argon, helium, or nitrogen.
- Use passive or active sorbent methods (can include gas, particles, water vapour, or oxygen sorbent). Change the sorbents periodically.

REDUCE REACTIONS on objects

- Decrease the level of RH, the temperature, or the ultraviolet, visible, and infrared radiation (where appropriate).
- Neutralize pollutants absorbed into the objects (e.g. alkaline compounds in papers inhibit acid deterioration).

REDUCE EXPOSURE TIME

- Limit exposure of objects to the inappropriate environment.

MONITOR the collection

- Inspect for signs of deterioration on objects and on the enclosure and building products periodically.

MONITOR pollutants in rooms and in enclosures

- Do appropriate in situ monitoring of pollutants.

MONITOR performance of control features

- Verify efficiency of the gas and dust filter systems periodically.
- Measure the leakage rate of the building and enclosures

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

RESPOND to the detection of pollutants or damage on objects

- Protect objects from the harmful environment, or monitor closely.
- Remove dust, efflorescence compounds or active corrosion compounds on objects.
- Re-evaluate the avoid, block, and reduce strategies; consider cost-benefit analysis.

Monitoring is an important element of the control strategy. However, methods for monitoring air quality in museums have not yet been standardized and are not extensively used, partly due to their high cost. This reinforces the function of the **Avoid and Block** strategies. When resources are available or when there is a specific important problem, **Airborne Pollutants** (Tétreault 2003) proposes an investigative approach. Detailed lists of commercial dosimeters can also be found in Grzywacz (2006). In the absence of monitoring equipment, visual inspection of the collection can be easily done. In a routine inspection, look for signs of new corrosion on metals, especially for those in new display cases or new storage cabinets. Off-gassing from fresh products in the enclosure may cause corrosion observable in only a few weeks or months. If the RH is maintained at high levels, or if there is high fluctuation, check for efflorescence, such as the formation of white powder or crystals on ceramic or shell object (Figure 6). The other signs of deterioration, such as discoloration, cracks and embrittlement, usually appear gradually, and the perception of change is difficult to assess without reference documentation. Accumulation of dust can also be monitored by placing clean glass plates in different locations. After a few months of exposure, a primary analysis of the nature of dust with an optical microscope can help to identify the main source in the specific location. The control strategies can be revised if the rate of deposit is unacceptable.

All the strategies above are for prevention mode. When a problem is noticed, it is necessary to respond by going into active mode. All objects at risk must be in a safe environment, or they should be removed to reduce exposure time. Close monitoring is necessary and, if it is considered that the compounds on objects resulting from the presence of pollutants may still be active, the damaged objects should be dealt with by qualified professionals. Once the cause has been investigated, the control strategies in place should be re-evaluated to prevent the same risk in the future.

Control strategies for different degrees of preservation

Certain typical sets of control strategies are grouped to fulfill three progressive degrees of preservation: basic, intermediate and advanced. Table 5 shows three different degrees of preservation for the majority of a collection. They are based mainly on making improvements in the selection of construction products, airtightness of enclosures and filtration of the fresh air intake. The degrees of preservation are not absolute, and can be adjusted as required.

Table 5. Control strategies for different degrees of preservation of mixed collection against airborne pollutants.

Degree of preservation	Control strategies
Basic	• RH < 75% [1] • In room: avoid high emissive products[2] such as freshly applied oil-based or alkyd coatings, cover large objects in storage with fabric and a plastic sheet. If an HVAC system is present, the filtration system should correspond to Class D[3]. Floors of traffic areas should be dusted every day.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Degree of preservation	Control strategies
	• and/or • In enclosure: avoid medium and high emissive products[2] such as dry oil-based coatings, or unsealed wood, or avoid using sulfur-based products inside display or storage cabinets. Let coatings dry 3 - 4 weeks before using the enclosure. Bag small items or put them in acid-free boxes or plastic boxes; or wrap them with a plastic sheet or with cotton fabric or acid-free tissues.
Intermediate	• RH < 65%[1] • In room: avoid high emissive products[2], use a climate control system (portable unit or HVAC system) with a Class B[3] filtration system. Floor of traffic areas should ideally be dusted with a vacuum cleaner having a good dust filter efficiency. • and/or • In enclosure: gaskets are used and joints sealed to improve airtightness of display and storage cabinets. Avoid emissive products[2]. In storage, use acid-free sleeves or boxes.
Advanced	• RH < 55%[1] • In room: avoid medium and high emissive products[2], use a climate control with a Class A[3] filtration system, HVAC system able to fulfill the filtration needs (depending on density of visitors, type of collection, permeability of the building or room). Limit access to visitors or staff. Floor of traffic area should be dusted with a vacuum cleaner with a high dust filter efficiency. • and/or • In enclosure: good airtight (estimated or measured at equal to or less than one air exchange per day) enclosure with a passive sorption system[4] or moderately leaky with positive active filtration system. Use no or very low emissive products[3], ideally tested or well characterized. Inert gas environment can also be considered.[5]
1. If not in conflict with RH required for overall collection. The % value is based on an average of a few weeks. For more information, see section on Incorrect RH. 2. Technical Bulletin 32 Products Used in Preventive Conservation. 3. Table 6. 4. Vignette 2. 5. Consult section on Pests.	

Control strategies may vary according to the preservation needs of specific objects or collections. The highly sensitive objects (mentioned above) should be identified to allow an appropriate degree of preservation. They will probably need tighter control strategies to achieve the same degree of preservation as for the rest of the collection.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Basic preservation

The basic level insures minimum preservation by proposing control strategies that minimise the risk of damage by airborne pollutants for a period of one to three years. The highest risks with airborne pollutants are usually from new products such as building or retrofitting display cases without proper selection of products, or without sufficient curing time before the installation of objects. Oak and similar woods, and oxidative polymerization coatings, such as alkyd and oil based paints, are the most common problem products that cause corrosion on metals and efflorescence on calcium-based objects. High peaks of RH (above about 70%) also initiate and accelerate corrosion.

Since the cleaning of objects can be difficult and time consuming, it is better to prevent dust deposit. In storage, fabric or plastic sheets should cover large-scale objects, and objects difficult to clean should be enclosed, both in storage as well as in exhibit areas. Conservation advice may be needed in removing particles on fragile surfaces.

Intermediate preservation

After fulfilling the basic level of preservation, museum staff may consider a greater level of preservation. The control strategies described in intermediate preservation allow a minimum risk of damage for a period of 10 to 30 years for medium sensitivity objects. The main emphasis is on reducing the infiltration of airborne pollutants into the building and into enclosures, as well as better selection of low emission products inside enclosures. The minimal particle filter efficiency for the HVAC system is Class B Table 6, which is based on the performance of MERV 14 for the final stage filter.

Table 6. Specifications for HVAC system Filter Systems (Tétreault 2003)

Class of speci-fication	First-stage particle filter, minimum efficiency based on			Gas filter	Final-stage particle filter, minimum efficiency based on			Return air[3]
	ASHRAE 52.2 (MERV[1])	Dust spot efficiency [2]	EN 779[2]		ASHRAE 52.2 (MERV)	Dust spot effi-ciency	EN 779	
AA	>12	>70%	>F6	1 or 2 stages	>16	>99%	>H10	filtered
A	11	60–65%	F6	1 stage	15	>95%	F9	filtered
B	10	50–55%	F5	1 stage (preferable)	14	90–95%	F8	filtered
C	9	40–45%	F5	None	13	80–85%	F7	filtered (pre-ferable)
D	8	30–35%	G4	None	12	70–75%	F6	un-filtered

1. MERV: Minimum efficiency reporting value from ANSI/ASHRAE Standard 52.2. This standard replaces the two previous American and European standard tests (Note Table note 2). MERV covers a range from 1 to 20, where 20 is the highest filtration control. A MERV of 17 and above is designed for the needs of an ultra pure environment, such as storage of radioactive materials and surgery rooms.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Class of speci-fication	First-stage particle filter, minimum efficiency based on			Gas filter	Final-stage particle filter, minimum efficiency based on			Return air[3]
	ASHRAE 52.2 (MERV[1])	Dust spot efficiency [2]	EN 779[2]		ASHRAE 52.2 (MERV)	Dust spot effi-ciency	EN 779	
2. Performance of the filter based on the atmospheric dust spot test ASHRAE 52.1 and EN 779 from the European Committee for Standardisation (included for reference). 3. Return air is filtered when it is recirculated through the filter system.								

Advanced preservation

When resources are available, or when the value of objects justify it, advanced preservation can be achieved by tighter control strategies. A high barrier membrane is used for the building, and careful selection of non-emissive products for airtight enclosures is practiced. Sorbents in active or passive mode can be used in enclosures (Vignette 2). Due to the tight control required, access to visitors can be limited in storage areas as well as, to a certain level and in certain situations, the exhibition areas. The goal of advanced preservation is to minimize the risk of damage for 100 years or more. In some cases, a dry and/or low oxygen environment can be chosen for display or storage of highly sensitive or high value objects to insure this level of preservation.

Pollutants transferred by contact

A pollutant on the surface of an object or product can be transferred by contact with another surface, usually causing discoloration or staining. The rate of staining depends on the quantity and mobility of the pollutant in the material and the porosity or the reactivity of the surface receiving the pollutant. To a certain extent, all objects are vulnerable to staining from contact with inappropriate products. Such stains can be hard to remove from porous or very fragile objects. The most typical products that tend to transfer stains by contact over time are unsealed woods (especially where there are knots), acidic paper or cardboard (Vignette 3), flexible PVC, sulfur-based plastic, soft polyurethane foam, most adhesive tape, some liquid adhesives, salt contaminated surfaces (such as contaminated bricks or stone floors), metals under humid conditions (stain organic materials and can cause galvanic corrosion on metal objects), and oily materials such as skin and leather, but also the fatty acids from staff and visitors. Cleaning products can be harmful if incorrectly used, for example, general building cleaning supplies can splash onto objects on exhibit and in storage, or compounds associated with cleaning and polishing objects can cause problems if used inappropriately or in too large quantities. Sometimes the residue left by polishing compounds is not readily visible.

Control strategies

Strategies to minimize the risk of staining by contact mainly concern avoiding inappropriate products/objects, blocking pollutant migration at contact points, or reducing the length of contact. Table 7 shows common strategies to reach three different degrees of preservation for contact with harmful products. The basic degree of preservation against damage caused by

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

contact for the first years; intermediate and advance levels will prevent damage for a few decades and for a few centuries respectively.

Table 7. Control strategies for different degrees of preservation of collection against damage caused by contact with harmful products

Degree of preservation	Control strategy
Basic	• avoid contact with sulfur-based products; do not use adhesives (except starch glue for paper artworks), or rubber bands in contact with objects; let the coatings dry 3 - 4 weeks on wood before contact with objects; do not use uncoated metal fasteners. • avoid placing the object on the soil, or on brick or ceramic floor contaminated with salts. • have clean hands or wear gloves for handling objects. Visitors should not be able to touch objects easily.
Intermediate	• use low permeability interleaves such as buffered papers or low permeability thin plastic sheet, such as PET (polyethylene terephthalate) or Melinex 516. Laminated aluminium foil will be also a very good impermeable thin interleave. • avoid contact with acidic products such as acid papers, flexible PVC and cellulose acetate sheet.
Advanced	• use products that do not contain and will not generate secondary pollutants over time, such as glass and recommended thick plastics.

Intrinsic pollutants

An intrinsic pollutant is one that is already in the object as part of its original content, or has been added during processing or treatment. Inherent deterioration is a term sometimes used to refer to the action of intrinsic pollutants in the object. Intrinsic pollutants are either unstable or they can react with other compounds in the object to cause damage. New compounds formed inside objects during a degradation process can also be considered as intrinsic pollutants or, more precisely, secondary intrinsic pollutants. A good example is acetic acid released by cellulose acetate film undergoing hydrolysis. The acetic acid formed within the film accelerates its degradation. In paper artworks, alum (used as internal sizing) tends to speed up the degradation of the paper. Objects treated with oily materials, such as leather dressings, can result in corrosion of attached copper parts (Figure 7).

Plasticizer in flexible PVC objects is also a common problem, but it is not really associated with an intrinsic pollutant. Somehow the plasticizer is unstable in the object and it tends to migrate to the surface of the object. The flexible PVC will become sticky and will deform while the plasticizer is leaving. Certain colorants in the plastic can be dissolved and migrate with the plasticizer to stain other parts of the object with which it is in contact. Reducing the temperature will help to slow down the migration.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Control strategies

If intrinsic pollutants are a feature of unstable artists' materials or manufactured products used in artworks, there is little that can be done to avoid them, except education. Blocking the pollutant within the object is often a solution. Deacidification of books in archives and libraries is a typical strategy, blocking the action of acidic compounds by adding alkaline compounds. Otherwise, the main strategies are limited to reducing the reaction by keeping objects cool and dry. Thus, the basic degree of preservation will consist of avoiding excesses of relative humidity, temperature and light.

Objects in the collection having intrinsic pollutants should be identified and special control strategies initiated before any serious and irreversible damage can occur. Some materials from objects composed of sulfur- based compounds, polyurethane foams, flexible PVC, wool (Figure 10), inadequate glue or cellulose acetate can cause damage to the object itself by off gassing or contact.

Figure 10. A 19th century coin balance stored inside its wooden case for many decades at the Augustiner museum, Freiburg. Wherever the wool threads were in close contact, the brass cups are blackened in lines. The nature of the black corrosion layer is unknown, but as part of the object, the wool was the source of pollutants or, at least, contributed highly to the damage. The contribution of the wood case to the corrosion is also unknown. Courtesy of Christoph Waller.

Vignette 1. Powdery white corrosion in storage

Problem: White, powdery corrosion was noticed on a medal. Examination showed that all the affected items were made of lead. This is the result of using products in the display or storage environment that emit carboxylic acids. Lead is particularly prone to corrosion from these acidic compounds.

Solution: Identify the source of pollution and deal with it. In this case, the oak paneling used in construction of the storage enclosures proved to be a source of acetic acid. Sealing the wood with acrylic latex paint with at least four weeks drying and ensuring basic control of the relative humidity can mitigate the problem. However, due to the sensitivity of lead to acetic acid and the probability of having high

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

levels of acetic acid released from products, it is advisable to avoid using such acidic products as wood, acidic paper, fresh paint or fresh emulsion glue in displays of lead objects.

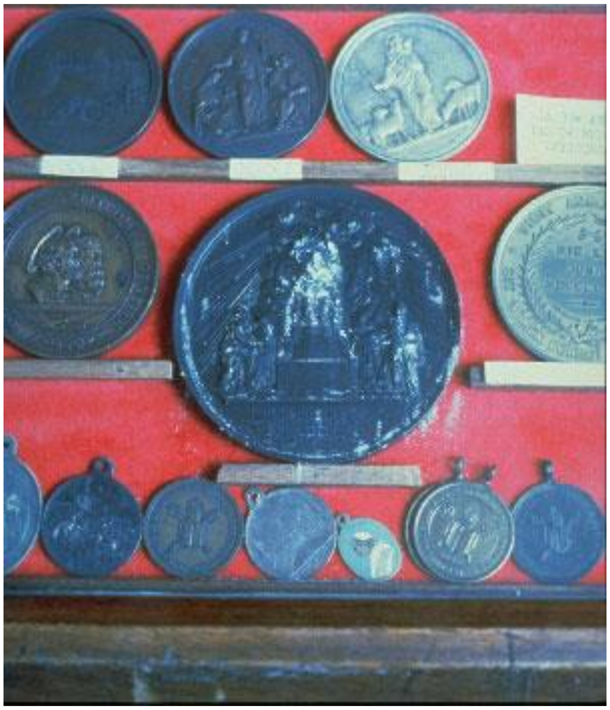

Figure 11. Corroded lead medals in an oak display case. Courtesy of the Musée du séminaire de Sherbrooke.

Vignette 2. Use of sorbents

Figure 12. Blend of pollutant sorbents. Photo courtesy of Purafil, Inc.

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Sorbents (or scavengers) can extract certain compounds present in the ambient air and retain them by an affinity, or reaction, process. A sorbent may work through absorption (interactions taking place largely within the pores of solids) or adsorption (interactions taking place on solid surfaces). The processes involved can also be divided into chemisorption (chemical bonding with the substrate) and physisorption (physical attraction, such as weak electrostatic forces). Desorption processes can also occur (assuming the sorbed gases have not already reacted) if the sorbent is close to equilibrium (between ambient pollutant's level and what the sorbent can absorb) and if the level of pollutants decreases in the ambient air. For good performance, the sorbent must be replaced or regenerated before it approaches the desorption process.

As a simple rule of thumb, in the case of a well-sealed enclosure (assuming one air exchange a day) **without** important emissive materials (objects and products), 500 grams of activated carbon per cubic meter can, for a period of one year, reduce the level of pollutants inside the enclosure by a factor of 10, as compared to the level in the room. After that, the carbon will need to be replaced. If the enclosure is more leaky, if there are substantial internal pollutants, or if the lifetime of the sorbent must be extended, more sorbent will be needed. In practice, the use of sorbents is recommended mainly when measures are already in place to minimize internal sources, and to maintain high level of airtightness of the enclosures.

For more details on the use of sorbents, see CCI Note 15/1 Care of Objects Made from Rubber and Plastic, or consult Tétreault (2003).

Vignette 3. Stain of paper artwork

Figure 13. Paper artwork stained by an acidic matboard after many years of contact.

This artwork on paper has been stained by the migrating component of an acidic tape (passe-partout) by contact over more than a decade. The stain is mostly irreversible. A buffered acid-free board should had been used instead. For long-term preservation, the use of acidic papers and cardboards, as well as metal staples or paperclips, rubber bands and adhesive tape should be avoided.

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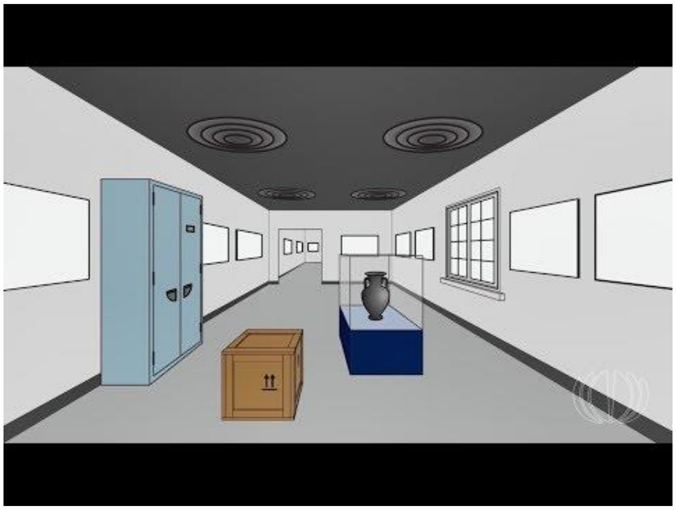
Vignette 4. Video



The use of commercial paints in museums

This video provides answers to the commonly received questions: what paint should be used to avoid any damage to museum collections and how long should a painted surface be left to dry before objects can be exposed to it? This video was created by the Canadian Conservation Institute.

Glossary

Enclosure

A collection of materials that surrounds a limited space (e.g. a plastic bag, display case, storage cabinet, or transportation box).

HVAC system

A heating, ventilation, and air-conditioning system that includes any interior surface of the facility's air distribution system for conditioned spaces and/or occupied zones.

Material

A substance that composes an object or a product, e.g. copper, oak, cotton are materials. See also **Object and Product**.

Object

An item judged by society, or by some of its members, to be of historical, artistic, social, or scientific importance. Objects can be composed of one or more materials, and can be movable (such as works of art, artifacts, books, archival-related items, and items of natural, historical, or

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archaeological origin) or immovable (such as architectural interiors or structures of historical or artistic interest).

Product

A manufactured or processed substance made up of one or more materials used in the care and housing of collections or objects. For example, plywood is a product made of two materials: wood and adhesive. Specifications for selecting products use a variety of terms such as inert, stable, safe (no or low risk), or suitable. These terms are not standardized, but "inert" almost always refers to a very high level of stability that is not usually mandatory in conservation. Otherwise, common recommended products such as acid free papers will have to be banned in conservation.

References

Grzywacz, C. M. **Monitoring for Gaseous Pollutants in Museum Environments**. Los Angeles: Getty Publication, 2006.

Key readings

Hatchfield, P. B. **Pollutants in the Museum Environment: Practical Strategies for Problem Solving in Design, Exhibition and Storage**. London: Archetype Publications, 2002.

Tétreault, J. Airborne Pollutants in Museums, Galleries and Archives: Risk Assessment, Control Strategies and Preservation Management, Ottawa: Canadian Conservation Institute. 2003.

Tétreault, J. "Guidelines for Pollutant Concentrations in Museums". **CCI Newsletter** 31 (2003) p. 3-5.

Thomson, G. **Museum Environment**, second edition. London: Butterworths, 1986.

Thanks to the Centro Nacional de Conservación y Restauración in Chile, the Canadian Conservation Institute's web resource Agents of deterioration, translated into Spanish by ICCROM, is now available free of charge. Intended for curators and conservators, the resource identifies 10 primary threats specific to heritage environments.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Light, ultraviolet and infrared

Stefan Michalski

The dilemma: Seeing versus saving

We need light in order to see collections, but light damages some objects. In terms of risk management trade-offs, we must make a decision that minimizes the loss of value due to poor visual access and the loss of value due to permanent damage. In terms of ethics and visual access, we must balance the rights of our own generation with the rights of all future generations. In terms of practical reality, we must generalize across a multitude of such decisions because objects differ in both their sensitivity to light and their visibility. In addition, display spaces in many museums depend on highly variable and poorly controlled lighting. This section examines the components of these decisions and offers some summary guidelines. However, the painful dilemma never disappears — seeing collections well today, and seeing them "well" in the future.

Quantifying light, UV, and IR

Light does not "contain" UV and IR

In the museum business, one often hears the expression "the light contains ultraviolet and infrared." This is incorrect and will lead to unnecessary confusion in practical discussions of museum lighting. Light, by definition, is the band of radiation to which our eye is sensitive. Ultraviolet radiation (UV) and infrared radiation (IR) are not visible. They are the bands of radiation on either side of the visible band (ultra means beyond, infra means below). Informally, the term radiation is dropped. We usually speak of ultraviolet and infrared, or simply of UV and IR. Ultraviolet and infrared are not necessary for seeing (except in rare cases of UV fluorescent colours); therefore, they are not part of the dilemma between seeing and damaging, they are simply damaging.

It is correct, however, to state that some light sources emit ultraviolet and infrared, or that museum lighting may cause UV and IR deterioration

The radiation spectrum

Figure 1 plots the adjacent bands of UV, light, and IR on the conventional scale of wavelength (in nanometers – nm). The reciprocal scale for photon energy is also shown (in electron Volts – eV) to show how photon energy climbs rapidly in the direction of the UV band.

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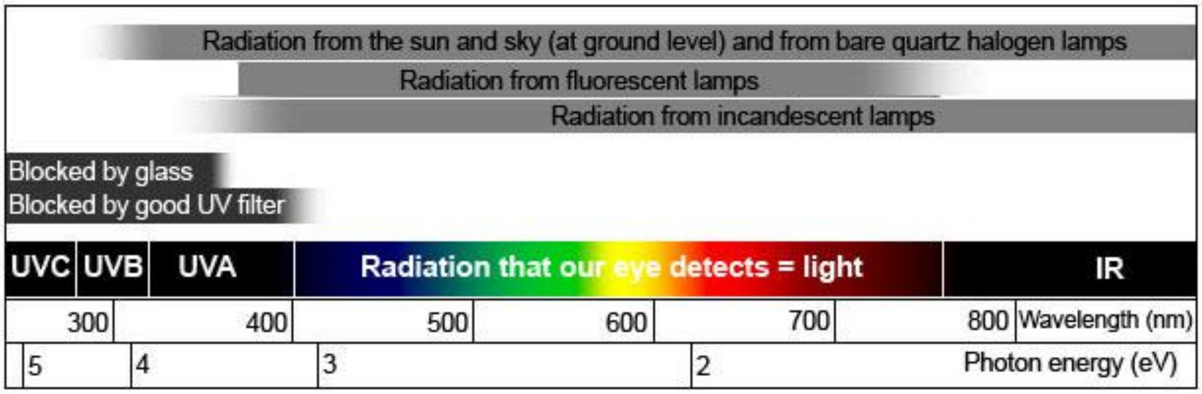

Figure 1. Radiation emitted by various light sources and the bands blocked by various UV filters.

Radiation bands emitted by various light sources are shown by light grey bands. Bands of radiation blocked by some filters are shown as dark grey bands. Convention assigns the boundary between UV and light at 400 nm, but slight perception begins at 380 nm. This boundary of 380 nm is often used by the window industry in rating the UV characteristics of glazing.

The different types of damage typical of UV, light, and IR result from their different photon energies. The photochemistry that underlies much of the disintegration of materials and production of yellow by-products typical of UV exposure requires energies greater than about 3 eV, whereas the photochemistry typical of colourant fading, as well as the operation of our retina, occurs in a range between about 2 eV and 3 eV. We are fated, in fact, to see in the same band as that which causes sensitive colourants to fade, given the related photochemical phenomena. Infrared photons are not energetic enough to initiate any of the forms of photochemistry driven by UV or light, so their effect is simply a heating of the surfaces that absorb them.

Measuring light and its exposure

The technical term for the amount of light falling on a surface is "illuminance," but informal phrases such as "light intensity" or "lux level" are used in the museum literature. The unit is lux (both singular and plural). Old light meters may still use the imperial unit "foot candles." Their readings can be converted to lux by multiplying them by 10 (10.76 precisely). Many companies make light meters, also called lux meters. Some of these meters are especially designed for museums so that they include UV and even RH and temperature measurement.

Figure 2 plots various situations and their lux levels across the vast range of the human eye, from moonlight to sunlight.

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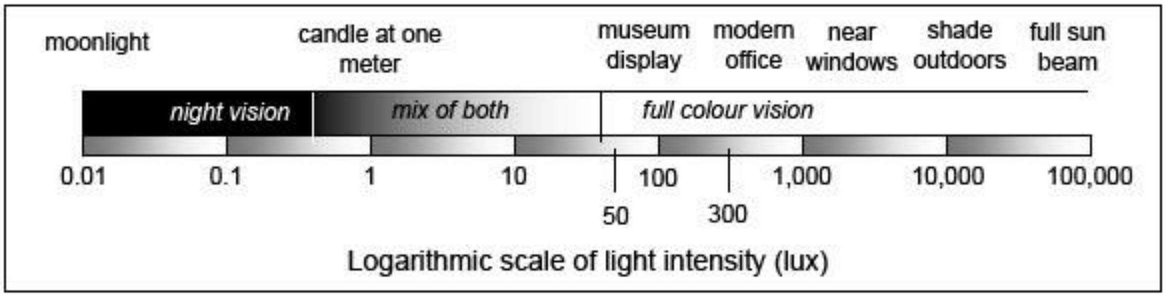

Figure 2. Various lighting situations and the transition from colour vision to night vision, plotted on the lux scale.

Our eye changes from night vision (scotopic) to colour vision (photopic), with a mixed range (mesopic) between. Rate of light damage is proportional to intensity; therefore, it increases 10 million times from moonlight to sunlight, and 1,000 times from good museum levels to sunlight.

The total exposure or dose of light on a surface is the product of light intensity (lux) and time (hours). In museums, the practical unit is millions of lux hours, abbreviated Mlx h, and pronounced "mega lux hours."

Measuring UV and its exposure

Rather than measure the intensity of UV directly, the convention in museums has been to measure it relative to the intensity of the light, in units of microwatts (of UV) per lumen (of light), abbreviated µW/lm. This ratio is much more useful than the direct measure of UV when characterizing light sources in a museum and characterizing the benefits of any UV filters on these sources. Various companies make UV meters for museums

Although some authors have suggested doing so, it has not been conventional to measure UV exposure in museums. One can express it if needed as a combination of the light exposure in Mlx h and the UV (ratio) in µW/lm, as will be done later in Table 5, Sensitivity to UV.

Measuring IR

There are no museum conventions or common instruments for measuring IR because it is not nearly as important as UV or light to collection damage. To make a simple instrument for measuring the heating potential of IR from a light source, paint the bulb of an ordinary outdoor glass thermometer with a matte black paint. Place the bulb in the light beam near the object and wait until the temperature stops rising (several minutes). To see if the temperature rise is a problem, refer to the section on Incorrect temperature. As a common-sense alternative estimate, place your hand in the light beam (at the point it might strike artifacts) and use a piece of cardboard to alternately illuminate and shade your palm. If you feel a noticeable warming due to the light, then those artifacts identified as sensitive to "temperature too high" in the section on Incorrect temperature will be at risk.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

How much light do we need to see?

The benchmark is 50 lux

When guidelines for museum lighting were first explored 60 years ago, colour science had established that 50 lux was enough to ensure that the human eye was operating well within the range of full colour vision (consult Figure 2); therefore, conservation adopted it as the benchmark level for museums. Since then, however, the public has voiced complaints about low light levels in museums. Although our responsibility for the future viewer will always force us to use low light levels for some objects, it is useful to understand the validity of the statement "I cannot see the objects."

A more precise description of our ability to see at 50 lux emerged in the 1980s, centred not simply on whether we could discriminate differences between patches of colour, but whether we could see the tiny details of an object. It emerged that a young person (age 25) viewing a moderately light-coloured object, with a moderate degree of detail, in a moderately complex pattern, in a reasonable period of time, will see all the details almost as well at 50 lux as they will in full sunshine. Unfortunately, they will not see those details as well as they can in sunshine if the object is dark, if the details are very fine, or if the pattern one is looking for within the details is subtle, and the viewing time is limited. Even more unfortunately, someone older (age 65) will need several times as much light to see as well as the youth, even with all necessary optical corrections such as glasses. Recent research has shown that even our ability to discriminate large patches of colour falters as we age.

Adjustments for everyone to see better

It is obvious to us all that we see tiny details much better in brighter light, especially if the object is dark, or the details very "soft" (i.e. low contrast), or when one is searching for subtle patterns in these details such as in an etching on handmade paper versus a good facsimile on machine-made paper. Our ability to see objects as real, genuine, and authentic, resides in our ability to see such details. One cannot imagine an institution more devoted to people "seeing the real thing" than a museum; hence, the complaints when they cannot. The question becomes, how much visibility of the real thing should a museum provide, given the steep cost to the lifetime of the objects? And how much more light does this increased visibility require?

Table 1. Adjustments to provide equal visibility of details.

Details	Adjustments
Benchmark value, reasonable visibility for young viewer:	50 lux
For dark surfaces:	Up to 3 times the lux
For low contrast details:	Up to 3 times the lux
For very fine details or complex time-limited task:	Up to 3 times the lux
For older viewers:	Up to 3 times the lux

Details	Adjustments
A combination of the above factors: multiply the factors; therefore, up to 3 × 3 × 3 × 3 × 50 lux, for a total of up to ~4,000 lux for an old person looking for subtle patterns in fine detail in a dark object.	

If we use the 50 lux benchmark, Table 1 summarizes some simple (and conservative) rules for adjusting visibility for different objects. For a technical summary of the research underlying these adjustments for visibility and the original sources, consult Michalski 1997.

Table 1 does not imply that a museum must make these adjustments, it simply describes the adjustments necessary to maintain good object visibility across various situations. Whether or not one adopts any of these adjustments for visibility depends on the balance with the preservation issues raised in the later sections on deterioration by light and UV. This balance forms the subject of the final section on "Control Strategies."

Adjustments for older viewers to see equally well

Our visual system is not so much a still camera as a video camera connected to a complex and dynamic processor. As we age, not only do the lenses in our eyes yellow and fluoresce, but more stray light is created from internal scattering, cones and rods decrease in number, and the neural processing deteriorates. This is above and beyond the issues of normal aging that can be corrected with glasses and age-related pathologies that cannot. The factor of times 3 given in Table 1, to give us equal visual access at age 65 as we have at age 25, is smaller than actually necessary, but it does provide most of the benefit.

Lighting design mistakes that reduce visibility

How can lighting mistakes reduce visibility, and why does it especially matter in a museum?

The human visual system has a range of many orders of magnitude — the steps in the lux scale of Figure 2 — but at any one moment, given a wide range of colour brightness in one scene, we can only adapt to a fraction of one such step. The three mechanisms involved in adjusting our sensitivity — neural adaptation, iris size adjustment, and photoreceptor chemistry — take between 200 milliseconds and an hour to adjust. In a museum, lighting designs that exceed our eye's ability to adjust over time and space can be considered a mistake. Given the price paid in fading for giving visual access, it makes sense to avoid lighting mistakes that reduce this access.

Direct glare: Block

As with oncoming headlights that dominate our eyes and diminish the visibility of the adjacent road, any bright lamp or window shining in our eyes will diminish the visibility of an object. Direct glare greatly exceeds the sensitivity range of our eye and forces it to adapt to the higher intensity.

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Block any such glare: on lamps, use extension tubes ("snoots"), baffles, and louvers; on windows, use shutters, curtains, or blinds. (New blind materials are available that maintain the view, but block almost all the intensity.) Complex exhibition routes with interior partitions and numerous display cases will require many hours of chasing down glare from lamps, re-aiming them, or blocking them. One of the advantages of a simple perimeter wall layout, whether a long 19th-century, barrel-vaulted gallery or a small 20th-century room (consult Vignette 2) is the reduction of such problems.

Reflected or veiling glare: Test it

Display cases and glazed picture frames form one of the most cost-effective preservation strategies in a museum; however, the reflections they cause can become one of the most vexing characteristics of museum displays. Few people can predict reflections from drawings, and few museums will change a display after it is built "just because of reflections." Test before fabricating final designs. Purchase an artist's stretcher, or other wooden frame, and stretch clear plastic wrap over it. Place the frame wherever you plan the display case or the picture under glass; have someone hold utility lamps where you plan the lighting; stand where you expect the visitor to stand; and then check the plastic sheet for any lamp reflections. Some reflection from overhead lighting is unavoidable. The goal is to move it below eye level for even the shortest visitors. The view from a child's height is often disastrous, hence some of their boredom.

Genuine anti-reflection glass is available, but at great cost (the coating is the same as used on camera lenses, computer monitors, and some eyeglasses). It has been used most often in framing important paintings in historic house museums, where avoiding window reflections may become impossible. Low-cost "anti-glare" glass relies on a slightly frosted surface, and only works well if placed directly against the painting; therefore, it is not recommended for museums.

Background contrast: Avoid it

Most old objects look brighter and less damaged when placed on a dark matte surface, than when placed on a bright glossy surface. Try it. The museum tradition of white surfaces everywhere, as somehow "neutral" for display rooms and cases must be re-examined. When judging the effect of "nice bright" walls, one must ask whether the collection itself looks bright, or just the space — at the expense of the objects. Backlit panels in displays, other than providing silhouettes, must be recognized as completely dysfunctional in terms of artifact visibility.

Visual adaptation: Support it

The eye adapts remarkably well to lower levels, but it does take several minutes (as we all know from entering a cinema theatre). Final adaptation can take up to an hour. Many museums that have been conscientious in their gallery lighting suffer from exhibit entrances that appear "closed" because they are so dark compared to the entrance foyer. Consider reducing foyer illumination. Whenever possible, design a transition into exhibit spaces so that visitors can adapt in stages. Perhaps illuminate the introductory didactic panels slightly brighter than the main part of the exhibit space, as an invitation and a transition (though not so bright that it becomes its own adaptation or glare mistake).

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Sources of light, UV, and IR

A "palette" of light sources for museums

One currently has a daunting range of options for museum lighting. Table 2 summarizes the advantages, disadvantages, costs, and other parameters of currently available light sources.

Table 2a: General characteristics of light sources for museums

Characteristic	Incandescent		Fluorescent
	Traditional	Quartz halogen	Traditional tubes
Voltage	220 V, 120 V	220 V, 120 V, 12 V, 6 V	220 V, 120 V
Common types and nomenclature	A19, R30, R40, PAR38 A: common round bulb R: reflector ER: elliptical reflector PAR: parabolic reflector Number refers to diameter in multiples of 1/8 in. (3 mm). Many manufacturer specialities, e.g. Flurospray. As of 1996, many R4 and PAR types no longer available due to energy legislation.	MR16, PAR20, PAR30, PAR36 MR: multiple reflector PAR: parabolic reflector Number refers to diameter in multiples of 1/8 in. (3 mm). MR16 types also referred to by three letters, e.g. B.A.B., E.X.N., etc. Q series: no reflector, number refers to wattage.	T5, T8, T10, T12 T: tube diameter in multiples of 1/8 in. (3 mm). F18, F20, F40, F96 F: fluorescent, number refers to wattage. Colour temperature often given by letter: CW: cool white WW: warm white CWX: cool white deluxe WWX: warm white deluxe "Daylight", and many trademark names for colour temperature
Lifetime, hours	A, R, PAR: 2,000, ER: 5,000+	2,000 typical, but very short lifetimes in some museum uses such as fibre optics have been reported. Confirm first.	10,000 typical
Cost (per lamp)	A: $2 R, PAR, ER: $5-$10	$5-$25	$5-$20 (varies as CRI)
Relamp cost (per year of 3,000 hr)	A: $3; R, PAR, ER: $7-$30	$8-$40	$1.5-$6
Colour temp (below 3000 K= warm light) (above 4000 K= cool light)	2700-2800 K typical, i.e. warm. Flurospray blue filter will increase to approximately 2900 K.	3,000 K typical, i.e. warm, but cooler than ordinary incandescent.	"warm white": 3000 K "cool white": 4200 K "daylight": 5000-6500 K Others as specified
Colour rendering index (CRI)	100, excellent. Dichroic reflectors (low heat) may reduce CRI. Note: incandescent lamps and daylight both score 100 by		CW, WW: 50–60, bad deluxe: 70–90, fair to good

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Characteristic	Incandescent		Fluorescent
	Traditional	Quartz halogen	Traditional tubes
excellent: 90 – 100 good: 80– 89 fair: 70–79 bad: below 70	definition of the CRI because both have a smooth "black body" spectrum, i.e. no missing parts between 400 nm and 760 nm. The low colour temperature of traditional incandescent lamps, however, sometimes provokes criticism in museums, especially for paintings created outdoors using blue colours. The increase from 2800 K to 3000 K with quartz halogen lamps eliminates most such criticism.		special types: 90–95, excellent
UV output μW/lm	75, low	Behind glass: 100–200, medium. Those labelled UV-STOP: 40, low.	Most 75-150, low to medium A few higher
UV filter possibilities	Not essential, but highly UV-sensitive objects would benefit from a UV filter.	Bare quartz bulb emits shortwave UV, blocked by plain glass envelope or safety filter. Museum quality glass UV filters $10-$50. Low-cost plastic filters must be at a distance from the hot bulb.	Plastic sleeve UV filters available. Ensure end caps are certified against fire risk (some have ignited). Alternatively, place UV filters on fixture diffuser
Fibre optic or lightpipe Application	Inappropriate	MR16 commonly used in fibre optic illuminators. Fibres will filter UV and infrared. Illuminator: $200–$500 From 1-10 separate fibre outputs per fixture typical, sometimes more.	Lightpipe shelves can be used in cases.
Main museum advantages	"A" types very low cost Fixtures low cost	Excellent variety of beam widths and wattages available. Best light spectrum overall. Low-voltage lamps can be wired without concern for shock hazard. Very low change in lamp output over lifetime of lamp.	Low-frequency relamping. Little heat from tube. Low energy consumption.
Main museum sisadvantages	Too bright at less than 1.5 m. Highest heat output of any lamps (not suitable inside cases). No narrow spots.	Bulbs are very hot, bare quartz bulbs can explode. High heat output. Lamp cost per hour can be high. Some low voltage fixtures very expensive. Bare wire designs create fire risk.	Too bright at short distances. Not easily directed in a beam. Most fixtures look ugly, lighting can be "flat."

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Table 2b: General characteristics of fluorescent light sources for museums

Characteristic	Fluorescent compact	HID (high intensity discharge)	White LED (light emitting diode)	Daylight
Voltage	220 V, 120 V	220 V, 120 V and higher	6 V, 12 V, 120 V, 220 V	Not Available
Common types and nomenclature	CFT: compact fluorescent tube. Manufacturers may use other letters, e.g. TL, XL, PL, SL. Sizes: 5W, 7W, 9W, 11W, 13W, etc. where the number refers to wattage. Colour temperature may be written 2800 K, or just 28 K.	HID: high intensity discharge; this class includes the following: M: mercury MH: metal halide S or HS: high pressure sodium Xenon Many elaborate shapes, fixtures. 70–1,000 W+	These are very recent additions to museum lighting options; therefore, information in this column is only preliminary. Currently available in many lamp housings, including those used by quartz halogen lamps, e.g. GU10.	Not Available
Lifetime, hours	10,000 typical	3,000–40,000+	10,000–80,000 (if 70% loss of intensity is failure).	Not Available
Cost (per lamp)	$10–$40 (varies as size, reflector)	Varies widely with size.	$5–$20, depending on power	Costs "hidden," high: initial building costs, maintenance costs, skylight leaks, energy costs heating/cooling.
Relamp cost (per year of 3,000 hr)	$3–$12	Not Available	~$0.50–$2.00 assuming 30,000h of current GU10.	Not Available
Colour temp (below 3000 K= warm light) (above 4000 K= cool light)	2700 K warm 3500 K 4100 K cool 5000 K cool	Mercury, metal halides: warm to cool available. Xenon almost mimics daylight 6500K.	3000-3500 K available.	Late afternoon: 3000 K Noon sunshine: 6000 K Blue sky: 9000–12,000 K Daylight: mix of above, standard is "D6500 K"
Colour rendering index (CRI) excellent: 90 – 100 good: 80– 89	Near 85, good Most compact fluorescent lamps are "triphosphor." their spectrum contains three sharp peaks tuned to our eyes'	Best metal halides are 80 (good) up to 90+(excellent), but most metal halides, mercury, sodium lamps are below 65, bad.	Vary greatly at present. Typically 70 (fair) for all white, 90 (good) expected soon for all white. 90	100, excellent

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Characteristic	Fluorescent compact	HID (high intensity discharge)	White LED (light emitting diode)	Daylight
fair: 70–79 bad: below 70	three colour receptors. They have been unjustifiably criticized simply because they are not smooth spectra.		possible with mixed colour LEDs.	
UV output µW/lm	100–150, medium	Most high to very high.	0–75, very low.	300–600 typical, very high
UV filter possibilities	Plastic film sleeve or cover must be custom fabricated if necessary.	Many use a glass UV filter against shortwave UV. This does not filter enough UV for museums. Plastic films can be used at some distance from the heat of the bulb.	Not necessary.	Window glass filters shortwave UV, but not enough for museums. Laminated glass with middle layer of UV filter available, or self-adhesive plastic films for windows. (Films may void warranty on sealed insulating glass windows.)
Fibre optic or lightpipe application	Not Available	Small MH or xenon lamps are used in some fibre optic illuminators. Whole rooms of cases have been lit by one powerful lamp in a separate area. This will reduce fire risk, theft risk, and total costs.	Could be used.	Lightpipes have been used for daylight transfer through buildings.
Main museum advantages	Very useful at short distances, such as display cases. Low frequency relamping. Little heat from tube.	Useful for lighting large areas and museum exteriors for security purposes.	Very useful at short distances, such as display cases. Easily aimed. Very low frequency relamping, low energy use (very economical). No heat in light beam (but lamp itself needs cooling).	Feels good, looks nice. Can provide very high intensities without high heat content. Can be (but often not) good in terms of sustainability and environment.

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Characteristic	Fluorescent compact	HID (high intensity discharge)	White LED (light emitting diode)	Daylight
Main museum disadvantages	Not easily directed in a sharp beam.	Most have terrible CRI. Most slow to start. Intra-batch variation high. Output can change significantly with ageing.	Currently CRI and lifetime, highly variable. Colour homogeneity of beam can be poor. Lamp intensity can drop early in lifetime.	Difficult to control intensity. Varies with the weather, seasons. Windows and their control fittings are expensive to build and to maintain. Can be energy expensive for building operation.

Colour rendering index

Colour Rendering Index (CRI) measures light quality in terms of the viewer's ability to see colours correctly. The scale has a maximum of 100 and no units. CRI is derived by a colourimetric calculation performed on up to 14 different colour samples illuminated by the light source in question, compared to the calculation using daylight or an incandescent lamp as reference. While recognized as imperfect in its correlation with our visual system, CRI is still the best indicator currently available.

There is no international museum standard on what is or is not an "acceptable" CRI, but the Canadian Conservation Institute (CCI) recommends a minimum of 85. Many museums specify greater than 90. That being said, the difference between a compact fluorescent lamp scoring 82, for example, and the guideline 85, is not noticeable by most people in most situations. If such a lamp has major design, cost, and energy advantages, it makes sense to use it. Light sources easily seen as poor, such as the lowest-cost commercial fluorescent lamps, can score below 60.

Note that daylight of CRI 100, after reflecting against a coloured wall or floor, may measure a far worse CRI than light that comes directly from a lamp of CRI 85. If one chooses to illuminate using "bounced" daylight (or any other light source), then the reflector must not be coloured.

Correlated colour temperature

Correlated Colour Temperature (CCT) measures the quality of light that passes from "cool" to "warm." This is not a scale of good to bad, unless one is arguing a personal preference for some types of object. The units are degrees Kelvin, abbreviated simply to K. The common terms for this parameter are, unfortunately, contradictory and confusing. A "cool" light source has a high colour temperature and a "warm" light source has a low colour temperature. This comes from our use of the phrase "warm light" to refer to the golden light of sunrise and flames, and "cool light" to refer to the blue skylight that illuminates shaded areas.

With low light levels, as in museums, viewers tend to prefer warmer light similar to that of incandescent lamps, e.g. the 2800 K of standard incandescent lamps, or the slightly higher 3000 K of quartz halogen incandescent lamps. As illumination increases to several thousand lux, preference is for cooler light, 5000

K or higher. The most common energy-efficient lamps (fluorescent lamps) are available in a wide range of colour temperatures. Successful use of compact fluorescent lamps in small museums requires careful attention to colour temperature. Lamps producing warm light, usually marked with 2800 K, or simply "28 K" are generally preferred at lower light levels, as noted earlier. However, lamps producing cooler light (3500 K up to 5000 K) can increase the colour contrast of objects, which may also be desirable. In conclusion, one should always test before making a final choice on colour temperature.

Natural versus artificial light

Proponents of daylight in museums often use the terminological trick of "natural" light to mean daylight, and "artificial" light to mean electric sources, but all light sources are natural, whether glowing stars, glowing filaments, or glowing phosphors. The correct question is whether the CRI is good enough, and, as noted above, both daylight and electric lights can be either good or bad in CRI. The psychological appeal of windows and skylights comes about from the connection to the outside and from the high intensity of the light (when the sun shines). Careful treatment of existing windows by solar screens, blinds, partially closed curtains, and outdoor shutters closed during peak daylight, can reduce the fading and glare risks, while leaving intact the highly desirable visual connection to the outdoors.

Deterioration by light, UV, and IR

Practical generalizations about deterioration by light, UV, and IR

Given the three distinct bands of radiation — light, ultraviolet, and infrared — one can make useful generalizations about the types of deterioration they cause in museums:

- Light fades (or "bleaches" colours). Those colours that fade can disappear within as little as a few hours of direct sunshine, or just a few years at low museum lighting (e.g. some felt tip pen inks, some colour photographs). Those that do not fade may last centuries in direct sunshine (e.g. ceramics, Minoan frescoes). All coloured objects fall somewhere between these two extremes.
- UV causes yellowing, chalking, weakening, and/or disintegration of materials. Chalking of paint media is often mistaken for pigment fading.
- IR heats the surface of objects, and thus becomes a form of incorrect temperature (too high), with all the damage possibilities outlined in the section on Incorrect temperature. IR will not be considered in any detail in this section.

There is some overlap in the forms of deterioration caused by light and UV. Light (especially violet) can cause some of the disintegration and yellowing listed under UV, but only in a few materials, and only very slowly in comparison to UV. In turn, UV does contribute to the fading of colours, but its contribution becomes dominant only for colours that are durable to light.

None of these overlaps reduces the practical reliability of the above generalizations. To reduce the fading of collections due to display lighting, especially the most rapid fading, there is only one option: reduce light exposure. Many museums, private donors, and their framers have assumed that the primary cause of fading is UV, and that a good UV filter would prevent their collections from fading. Some advertisements for UV filters imply the same. For colours that are sensitive to light — the crux of the museum lighting dilemma — UV usually contributes less than half of the fading and often only one tenth; therefore, it does not allow one to think any differently about reducing light exposure. (The exposure scales in the centre of Table 3 quantify this phenomenon.)

Why bother, then, with UV control? Because for many artifacts, such as paintings with permanent pigments or monochromatic prints and drawings, the yellowing and disintegration of the media and support by UV is the major form of deterioration suffered during uncontrolled museum lighting.

Rates of light deterioration

Light damages the colours of some objects — most such colours fade (most of the colours in Figure 3a and 3b) and a few darken (the vermilion in Figure 3a). Table 3 summarizes the available data on the rate of this damage. Coloured materials are divided into four broad categories of sensitivity to light: none; low; medium; and high. For each category, the table provides estimates of the time it takes at various lux levels for the fading to start (first be noticeable) and for it to end (almost no original colour left). One can see that although the range, or uncertainty, within a category is very wide, the differences from one category to the next are much wider. Much of the variation in people's perception of whether light fading is a risk or not arises because this range of sensitivity is so dramatic — some colours in old objects that look fragile can indeed last many centuries, while some colours disappear within our own lifetime, or even in just a few years.

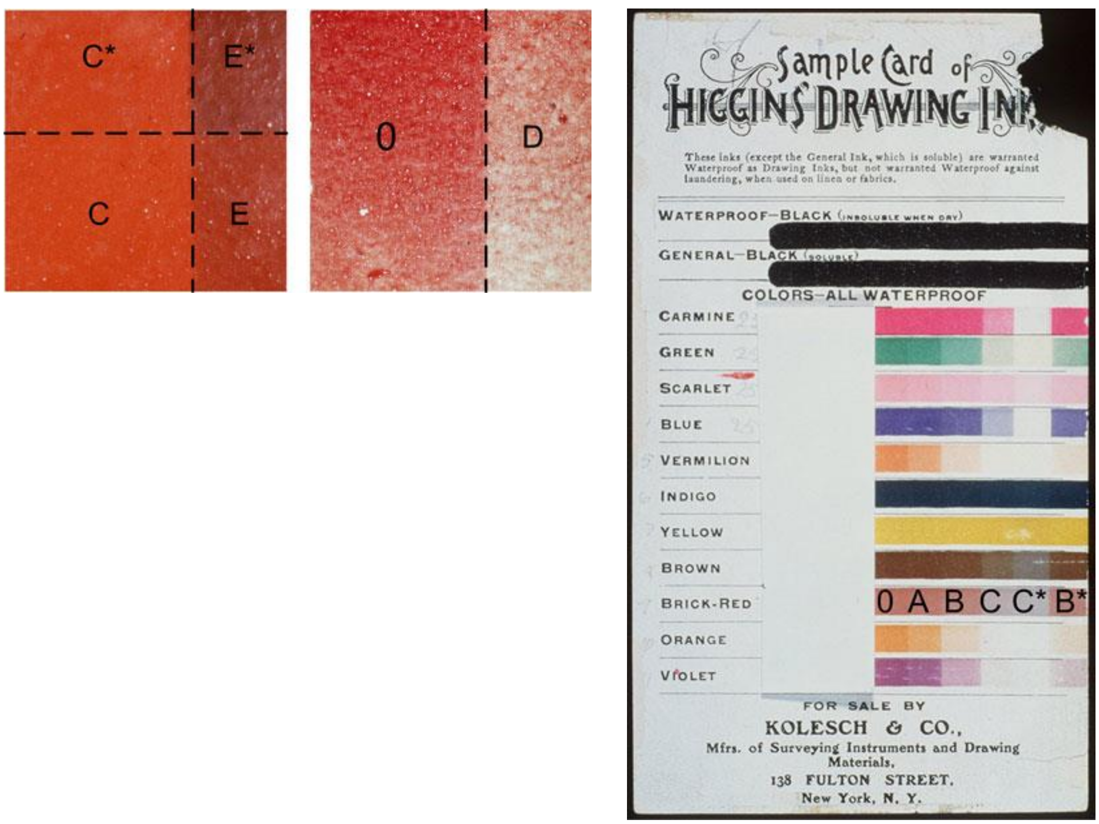

Figure 3a and 3b: Light, UV, and IR Examples 3a and 3b of light damage. Examples of light damage from controlled fading experiments, using a light source simulating daylight through glass, i.e. high in UV content. All samples taken from early 20th century sample books for artists.

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(3a) Oil paints, on the left vermilion darkening and; on the right, carmine lake glaze on white, fading. (3b) Drawing inks on paper, all fading. The letters on the samples indicate the following exposures: 0 - unexposed; A - 0.17 Mlx h; B – 1.7 Mlx h; C – 6.2 Mlx h; D – 17 Mlx h; E – 67 Mlx h. Equivalent exposures range from A: 1 day of sunlight or 1 year at 50 lux to D: 8 months sunlight or 400 years at 50 lux. All areas are protected by a UV filter except areas marked with an asterisk (*). Note that the differences between the presence or absence of a UV filter (B vs. B*, C vs. C*, D vs. D*), while sometimes noticeable, are much less significant than differences between different exposures (A vs. B vs. C vs. D).

Table 3: Sensitivity levels and fading
Sensitivity of coloured materials to light and the number of years to cause fading.

No sensitivity	Low sensitivity	Medium sensitivity	High sensitivity
Materials that do not change colour due to light. (These materials may change colour due to ageing or pollutants.) Most but not all mineral pigments. The "true fresco" palette, a coincidence with the need for stability in alkali. The colours of true glass enamels, ceramics (not to be confused with enamel paints). Many monochrome images on paper, such as carbon inks, but the tint of the paper and added tint to the carbon ink are often high sensitivity. Paper itself must be cautiously considered low sensitivity. Many high-quality modern pigments developed for exterior use, automobiles.	Materials rated ISO Blue Wool #7, #8 (and higher). Artists palettes classified as "permanent" (a mix of truly permanent AND low-light sensitivity paints, e.g. ASTM D4303 Category I; Winsor and Newton AA). Structural colours in insects (if UV blocked). A few historic plant extracts, especially indigo on wool. Silver/gelatine black-and-white prints (not resin coated paper) assuming all UV blocked. Many high-quality modern pigments developed for exterior use, automobiles. Vermilion (blackens due to light).	Materials rated ISO Blue Wool #4, #5, or #6. Alizarin dyes and lakes. A few historic plant extracts, particularly madder-type reds containing primarily alizarin, as a dye on wool or as a lake pigment in all media. It varies throughout the range of medium and can reach into the low category, depending on concentration, substrate, and mordant. The colour of most furs and feathers. Most colour photographs with "chrome" in the name, e.g. Cibachrome, Kodachrome.	Materials rated ISO Blue Wool #1, #2, or #3. Most plant extracts, hence most historic bright dyes and lake pigments in all media: yellows, oranges, greens, purples, many reds, blues. Insect extracts, such as lac dye and cochineal (e.g. carmine) in all media. Most early synthetic colours such as the anilines, all media. Many cheap synthetic colourants in all media. Most felt tip pens including blacks. Most red and blue ballpoint inks. Most dyes used for tinting paper in the 20th century. Most colour photographs with "colour" (or "color") in the name. e.g.

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No sensitivity		Low sensitivity	Medium sensitivity	High sensitivity
				Kodacolour, Fujicolour.
Exposure amount	**Fade amount**	**Time in years for fading**		
50 lux	Just noticeable fade	300 – 7000 years	20 – 700 years	1.5 – 20 years
	Almost total fade	10,000 – 200,000 years	700 – 20,000 years	50 – 600 years
150 lux	Just noticeable fade	100 – 2,000 years	7 – 200 years	1/2 – 7years
	Almost total fade	3,000 – 70,000 years	200 – 7,000 years	15 – 200 years
500 lux office	Just noticeable fade	30 – 700 years	2 – 70 years	1/7 – 2 years
	Almost total fade	1,000 – 20,000 years	70 – 2,000 years	5 – 60 years
5,000 lux window or study lamp	Just noticeable fade	3 – 70 years	2 months – 7	5 days – 2 months
	Almost total fade	100 – 2,000 years	7 – 200 years	6 months – 6 years
30,000 lux average daylight	Just noticeable fade	6 months – 10 years	2 weeks – 1 years	1 day – 2 weeks
	Almost total fade	20 – 300 years	1 – 30 years	1 month – 1 years
Each day of exposure is assumed to be 8 hours, each year 3,000 hours. Time for a "just noticeable fade" is given as a range based on the doses for the range of ISO Blue Wools in that sensitivity category (consult Table 4). The "almost total fade" is based on a conservative estimate of 30× the "just noticeable fade," although fading often slows down, so that an estimate of 100×, the just noticeable fade is probable for many colours.				

The broad sensitivity categories of Table 3 (high, medium, and low) were adopted in a recent international guideline for museum lighting (CIE 2004). They are defined using the industrial lightfastness standards known as the ISO Blue Wools. These are a set of textiles, originally numbered #1 to #8, each about 2 to 3 times as sensitive as the next. High sensitivity was defined as materials rated #1, #2, or #3; medium as #4, #5, or #6; and low as #7, #8, or higher (more were added to the original eight Blue Wools as needed by industry). The Blue Wool numbers are the main route into the literature on colourant sensitivity, as reviewed in Michalski (1987 and 1997) and as summarized in a more detailed version of Table 3 contained in the CIE guideline (2004).

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

The conversion of a Blue Wool rating into an estimate of the light exposure that will cause just noticeable fading is provided in Table 4, derived from a review of the literature partially described in Michalski (1987). The estimates in Table 4 are the basis of the time to fade estimates in Table 3.

The Blue Wools as an estimate of the range of sensitivities in collections

Museums inevitably ask, what is the range of colourant sensitivities in my collection? The original eight Blue Wools, developed in the 1920s, represented the sensitivity range that the dye and colourant industry knew was reflected in all the coloured goods of the time, whether using natural dyes, synthetic dyes (started in the 19th century), or even pigments. Thus the range of these eight Blue Wools is an excellent estimate of the range of light-fading sensitivities one might expect to find in a mixed museum collection. Of course, some coloured objects are not sensitive at all. Some coloured objects are even more sensitive than #1 because they were not intended to last even as long as a poor-quality textile, e.g. some felt tip pens.

Table 4: Approximate light dose to cause a "just noticeable fade" of the ISO Blue Wool standards ("Just noticeable fade" is defined here as Grey Scale 4 (GS4) as used in the Blue Wool data. The uncertainty in each dose estimate ranges approximately to the estimates of the adjacent Blue Wool.)

Detail	Light dose (Mlx h) to cause a "just noticeable fade" of the Blue Wool standards							
	ISO Blue Wool number #8	ISO Blue Wool number #7	ISO Blue Wool number #6	ISO Blue Wool number #5	ISO Blue Wool number #4	ISO Blue Wool number #3	ISO Blue Wool number #2	ISO Blue Wool number #1
Dose for "just noticeable fade" if UV present	120	50	20	8	3.5	1.5	0.6	0.22
Dose for "just noticeable fade" if UV removed	1000	300	100	30	10	3	1	0.3
Sensitivity category used in Table 3	Low sensitivity		Medium sensitivity			High sensitivity		

Rates of UV deterioration

The disintegration of organic materials caused by UV takes many forms, such as the weakening of textile fibres, the weathering of wood and bone, and the chalking of paints shown in Figure 4. Yellowing caused by UV is most easily seen in poor-quality plastic and paper such as newsprint. Table 5 summarizes the various effects and rates of damage known for UV. It begins with the benchmark of what we know from outdoor daylight exposure studies and extrapolates to the lesser UV exposures due to filtration by glass and by UV filters.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

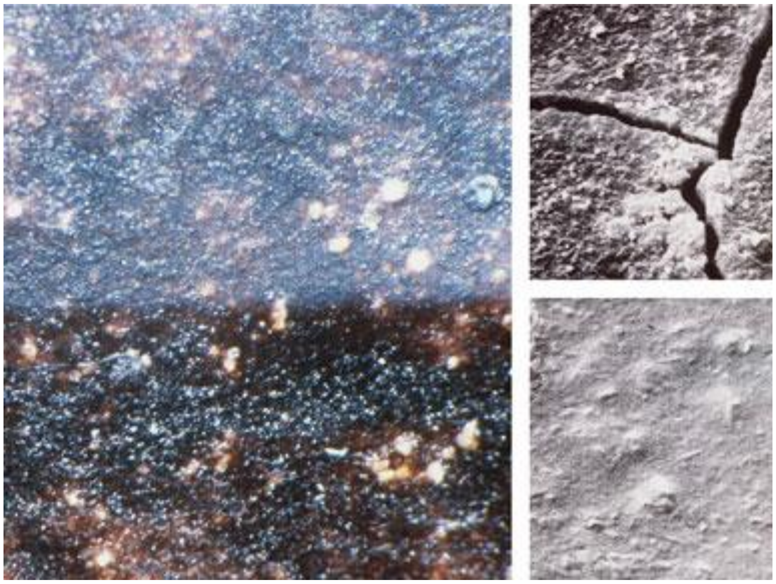

Figure 4: Light, UV, and IR Examples of UV. Examples of UV damage. Tests on an early 20th century burnt umber oil paint.

The images are all for an area exposed to 67 Mlx h of a light source similar to daylight through a window (equivalent to about 8 months full daylight, or 400 years of display at 50 lux). On the left is an optical microscope view. The bottom half was protected by a good UV filter. The black-and-white images to the right are scanning electron micrographs of the top and bottom areas. The lower image shows the smooth oil medium surface undamaged by UV and the upper image shows the eroded and cracked surface damaged by UV. The brown (mineral) pigment is not affected by either light or UV.

Table 5. Sensitivity of materials to UV.

<table>
<tr><th colspan="2">No sensitivity</th><th>Low sensitivity</th><th>Medium sensitivity</th><th>High sensitivity</th><th>Very high sensitivity</th></tr>
<tr><td colspan="2">Inorganic materials: metals, stone, ceramics, glass. (Treated or coated objects of this type may contain resins and paints of higher sensitivity.)</td><td>Cracking, chalking of modern plastics, rubbers, paints that contain UV stabilizers, designed for outdoor exposure.</td><td>Wood turns grey, erodes.
Cracking of most plastics, resins, varnishes, rubber.
Chalking of most indoor and artists' paints, ivory, bone.
Weakening and eventual fragmentation of most wool, cotton, silk, paper.</td><td>Chalking of oil paints with photosensitizing pigments (zinc white, early titanium white).
Yellowing of pale woods.
Weakening and eventual fragmentation of wool, cotton, silk, paper, if photosensitizing dyes present.</td><td>Yellowing of some low quality papers, such as newsprint.</td></tr>
<tr><th>Daylight</th><th>Lux amount</th><th colspan="4">Approximate time to cause damage described above</th></tr>
<tr><td>Daylight spectrum</td><td>Daily outdoor average:</td><td>~10 years</td><td>~1 years (wood erosion: 50µm of surface per year)</td><td>~1 month</td><td>~3 days</td></tr>
</table>

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No sensitivity		Low sensitivity	Medium sensitivity	High sensitivity	Very high sensitivity
~600-1000 µW/lm	30,000 lux				
	50 lux	~5,000 years (thermal ageing[1] likely in 100–1,000 years at 20°C)	~500 years (thermal ageing[1] likely in 100–1,000 years at 20°C)	~50 years	~5 years
Daylight through window glass, ~400-500 µW/lm	Full daylight 30,000 lux	~30 years or more[2] (thermal ageing[1] likely in 5–50 years at 40°C) [3]	~3 years or more[2] (thermal ageing[1] likely in 5–50 years at 40°C) [3]	~2 months or more[2]	~1 month or more[2] (thermal ageing[1] likely in 2 years at 40°C) [3]
	50 lux	~20,000 years or more[2] (thermal ageing[1] likely in 100–1,000 years at 20°C)	~2,000 years or more[2] (thermal ageing[1] likely in 100–1,000 years at 20°C)	~100 years or more[2] (thermal ageing[1] likely in 100–1,000 years at 20°C)	~50 years or more[2] (thermal ageing[1] likely by ~30 years at 20°C)
Daylight with good UV filter ~75 µW/lm or less	Full daylight 30,000 lux	~300 years or more[2] (thermal ageing[1] likely in 100–1,000 years at 20°C)	~30 years or more[2] (thermal ageing[1] likely in 5–50 years at 40°C) [3]	~2 years or more[2] (thermal ageing[1] likely in 5–50 years at 40°C)[3]	Bleaching by blue light overrides any residual UV yellowing (thermal yellowing may eventually prevail)
	50 lux	~many millennia (thermal ageing[1] likely in 100–1,000 years at 20°C)	~many millennia (thermal ageing[1] likely in 100–1,000 years at 20°C)	~many millennia (thermal ageing[1] likely in 100–1,000 years at 20°C)	

1. Thermal ageing (yellowing, weakening, cracking) refers to chemical decay processes that are not driven by UV (though sometimes initiated by a little UV), but which occur even in the dark at room temperature (consult Incorrect temperature).
2. The time estimates given are uncertain extrapolations from the full daylight spectrum estimates noted in the first two rows, based on available damage spectra. The numbers provided are cautious. The phrase "or more" means that the actual time for most material–lighting combinations may be many times longer. Exposure is assumed to be approximately 8 hours per day, 3,000 hours per year.
3. Organic materials exposed to sunlight can reach 40°C (even higher if the surfaces are dark or under glass). This increases the rate of thermal decay by a factor of at least 20 compared to 20°C.

Note in Table 5 the strong role of reduced light intensity, not just the degree of UV filtration, in extending the lifetime of materials on display. When UV is measured as a ratio — microwatts (of UV energy) per lumen (of light) — then the total UV exposure, and the damage that depends on it, is proportional to both the intensity of the lighting and the UV measurement.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Rates of IR deterioration

Infrared causes heating (considered in detail in the section Incorrect temperature). IR heating usually becomes a problem only with two sources of light: incandescent lamps at high intensity, over 5000 lux, and direct sunlight. In Table 5, nominally about UV damage, the effects of elevated object temperatures by direct sunlight are noted in the rows for average daylight through window glass. Sunlight, or intense incandescent lighting, can warm surfaces 40°C above ambient, or more. This elevates the rate of thermal decay by a factor of 20 or more.

When light, UV, IR, and other agents of deterioration mix in the same object

Different deterioration phenomena often occur simultaneously: the yellowing or weakening caused by UV can be mixed with similar effects caused by thermal ageing. This thermal ageing is, in turn, accelerated by the high temperatures possible with IR (as noted in Table 5). On top of that, some of the new yellowing may be faded by light (blue light in particular). All of us have seen old framed prints with various patterns of yellowing. These provide an interesting amalgam of agent effects. To begin with, any coloured paints and inks may be faded by light. The paper may be yellowed by UV that the glass does not block, but under the matt, it will be protected. In extreme exposures, the fibres of the paper weaken (often not noticed until such prints are handled or washed during conservation treatment and the image area begins to disintegrate). If the matt is of poor quality, it will emit vapours that cause a narrow band of yellow/brown near the edge of the matt, which is greatly accelerated by IR heating. If a good UV filter is present, the paper in the image area will become whiter, not yellow, but the region under the matt will become uniformly yellow from thermal yellowing, which is accelerated by IR heating. The permutations may be complex, but the conclusions are simple: for organic materials, keeping the light intensity below many thousands of lux will reduce all forms of light, UV, and IR damage. In addition, using low UV light sources will push UV damage of high-sensitivity materials well below the similar forms of damage caused by room temperature itself.

Control of light, UV, and IR

Stages of control

Avoid

- Establish rules for light levels, UV levels, and light sources (see the "Control strategies" section below).
- Bring outdoor objects indoors.
- Switch off electric lights whenever no viewer is present. Use proximity switches whenever possible.
- In historic houses, select locations in the house, and within the room, that are low in light intensity throughout the day. If there are no UV filters on the windows, place objects where no direct light from the window can reach them.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Block

- Use UV filters on light sources that are high in UV (as indicated in Table 2).
- Outdoors, use shading devices such as simple roofs or take advantage of the north side of a building.
- Indoors, use screens, louvers, blinds, solar screen, paint, etc. to block windows.
- Separate bright public access areas from display areas and provide adaptation paths between the two.
- Close curtains, blinds, shutters, etc. when the museum is closed. Cover cases when no viewers are present.

Detect

- Look for signs of light and UV damage in the museum.
- Use light meters and passive dosimeters.
- Use museum UV meters.
- Use a simple thermometer, if an IR heating problem is suspected.

Respond

- When faded objects are noted, determine causes and possible solutions.
- When light meters and UV meters show unexpectedly high values in a location, determine causes and solutions.

Recover

- There is no true recovery possible from faded colours or disintegrated surfaces. Restoring such losses requires replacement by new material.

Control strategies for different degrees of preservation

Introduction to different degrees of preservation

We can all agree on the general museum goal of reducing light damage at the same time as giving visual access, but, in practical terms, how much of each becomes a matter of increasing difficulty. There are three strategies, increasingly effective, but increasingly difficult:

- Follow a few basic measures designed to eliminate the extremes of light exposure.
- Follow a simple rule based on the light intensity for minimum visibility, 50 lux.
- Follow a few difficult rules to both minimize damage and maximize visibility.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

A basic strategy for small museums: Eliminate all extreme light exposures

From the List of Basics introduced in section I those that influence light and UV:

- A reliable roof that covers all organic artifacts (and preferably most inorganic artifacts). While this is obvious to even people outside museums, it also applies to large objects, such as historic vehicles or historic machines with paint. They cannot be expected to survive many years if exposed to sun and weather.
- Reliable walls, windows, and doors that block local weather, sunlight, local pests, amateur thieves, and vandals.
- Avoid areas of direct sunlight and intense spot lamps at close distances on all organic artifacts.

Results from the basic strategy

Assuming these measures avoid the extremes of 30,000 lux of average daylight, and fall somewhere between the 5000 lux of windows and the 500 lux of most office lighting, then low-sensitivity objects on display for a century will still appear colourful. Medium-sensitivity objects will have faded already in little more than a decade, and high-sensitivity objects will have been destroyed long ago, unless they were serendipitously set aside in dark forgotten places, boxes, envelopes, dowry chests, bound in volumes, etc., or were recently acquired from such places to be put on museum display. This is the tragedy of small historic house museums that acquire colourful new treasures from donors who had kept them in dark storage.

The traditional rule-driven strategy: Light everything at a fixed, low intensity

The traditional museum lighting rules, as contained in various publications of the 1970s and 1980s including CCI's own Technical Bulletins, were based on the 50 lux benchmark and added two extra categories for presumed differences in sensitivity:

- 50 lux for textiles, works on paper, watercolours on any medium, photographs, feathers, etc.;
- 150 lux for all oil and acrylic paint surfaces, polychrome, panels, furniture, etc.; and
- 300 lux for stone, metal, etc., primarily to avoid contrasting lighting.

Different authors' lists tended to differ somewhat regarding which items were in which category, and whether to include the 300 lux category.

The traditional rule on UV was as follows:

- Keep all UV levels below 75 µW/lm (the value for ordinary incandescent lamps).

The maximum acceptable UV level was established in the 1970s, based on the UV emitted by ordinary incandescent lamps. Experience indicated that these light sources provoked very little if any UV damage on mixed historic collections over many decades, given low-light intensities.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Furthermore, common practice tended to add these rules as well:

- Exposure times were defined primarily by operational considerations.
- Objects with components of many different sensitivities were defined by their weakest component.

Results from the traditional rule-driven strategy

The traditional lighting policy underlies most current lending and borrowing requirements. It reduces damage across all collections (as compared to normal building light levels), but high-sensitivity artifacts will still fade significantly within a few decades and low-sensitivity artifacts will be difficult to see for no good reason (except the simplicity of simple rules). If objects are dark, of low contrast, or highly detailed, they will, in fact, be impossible for many to see meaningfully at all. The presumed difference in sensitivity of the two categories — paper and textiles versus paintings and polychrome — is not warranted. While one might argue that the average watercolour is more sensitive than the average oil painting (due to the preponderance of thin washes), the fact remains that one can find large and important groups of contrary examples. All portraits in oil of the last several centuries depend on red lakes of high-to-medium sensitivity. When these fade (as many have already), the colour of the skin of the subject changes from the original, rosy "living" colour to a "dead" white colour. Conversely, whole classes of paper objects have been made with low or even zero sensitivity colourants, such as carbon blacks, ochres, white chalks, etc.

A risk-management strategy: Accept and manage fading and visibility

A detailed lighting policy within a larger risk-management framework acknowledges explicitly that colourants fade and that visibility improves with more light, and then develops a policy based on the following steps:

1. Establish a criterion for an acceptable rate of fading (acceptable risk). This is usually expressed as the time period that causes just noticeable fading. This might be selected as 100 years, or 30 years, or 300, etc.
2. Assess sensitivities. At the moment, this tends to large generalizations not unlike the groupings of the traditional rules above, such as "watercolours," but it can incorporate more detailed assessments, such as important sub-groups, a certain genre, or even a particular object of great value, using information such as in Table 3. Generally, the highest sensitivity colourant found, or expected, characterizes the whole group.
3. Consider visibility. Begin by assuming the 50 lux benchmark, but if a collection does not contain any high- or even medium-sensitivity colourants, one can consider adjusting lux levels upwards, based on Table 1. One can also consider mixing short periods of better visual access with long periods of minimal visual access, especially to accommodate older viewers, or special inspections by scholars.
4. Consider the lux levels practically available, given the lighting equipment.
5. Determine display time. This is the inevitable result of calculating what display rotation will keep fading within the acceptable fading criterion set at the start. For example, from Table 3, the shortest time required to reach a just noticeable fade of the high-sensitivity category is 1.5 years; therefore, high-sensitivity colourants can only be on display about 1.5% of the time, given the 100 year criterion set at the beginning.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

At present, policies following similar steps have been described by the Montreal Museum of Fine Arts (Colby 1992) and the Victoria and Albert Museum (Ashley-Smith et al. 2002).

In small museums and historic houses, where little or no light control exists, the steps vary slightly:

1. As above, recognizing that perhaps the museum mandate for preservation is not the same as that of a national museum.
2. As above, recognizing that a smaller museum can often get to know its collection better than a national museum.
3. As above, recognizing that on the one hand, visitors to a smaller community museum may be older on average and, on the other, that visitors may expect less visibility in a historic house setting.
4. Assess the light intensities, or cumulative exposures, in different display areas.
5. Determine display time possible in the locations under consideration for the artifact, given 1, 2, and 4. Balance where something is displayed, and how long it can be displayed there, or change your criterion in 1.

Optimum strategy: Results

The museum will manage explicitly the lifetime of the colours in its collections, at the same time as increasing the visibility of the many objects on display that are low or even zero sensitivity. This strategy requires considerable investment of expert knowledge and will provoke custodial anxiety due to uncertainty. For example, exactly how low is the sensitivity of a black-and-white photograph or carbon ink lithograph – at least hundreds, possibly thousands, of times lower than the average colour photograph or chromolithograph, and much more likely to be damaged by pollutants or thermal ageing before being affected by permanent display at 500 lux (using good UV filters). It also requires considerable labour to assess large collections. In current practice, this method will probably be used only to augment the simple rule-driven strategy — such as developing exhibition policies of reduced exposure time for high-sensitivity materials and examining explicitly the display of any especially valuable artifacts. Widespread use of this method will only become possible with the gradual accumulation and dissemination of the sensitivity distributions of useful categories, such as the palette of a particular artist's works, the costumes of a particular period, the photographs of a particular manufacturer, etc.

To help make such decisions using a risk management strategy, CCI has developed a light damage calculator for the web. It allows one to explore quickly the likely fading of different objects under a wide range of lux levels and display schedules. As sensitivity data is provided by researchers worldwide, it will be made available through this web page.

Conclusions

"Seeing versus saving" is the epitome of the "use versus preservation" dilemma faced by museums. We depend on light for sight, but the fading is utterly irreversible. In the past, museums relied on a simple rule derived from the "adequate" visibility of 50 lux. Loan agreements and governmental guidelines still reflect that rule. Museums with full control of their lighting behaved as if conformity to such rules meant the fading risk had vanished. Perhaps they had reached the point where their anxiety had been allayed by a workable compromise that could be codified. Small museums with less ability to control lighting were given no guidance on which objects were truly at risk from intense light and which were not. Moving beyond a rules-based or fatalistic approach, towards a strategy of risk assessment (aided by the CCI light

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

damage calculator) smaller museums will be able to focus their efforts, to place artifacts strategically within the varied light levels of their rooms, and to relax where the fading risk is small or non-existent.

Vignettes

Vignette 1. Use of a window well in a historic house for display

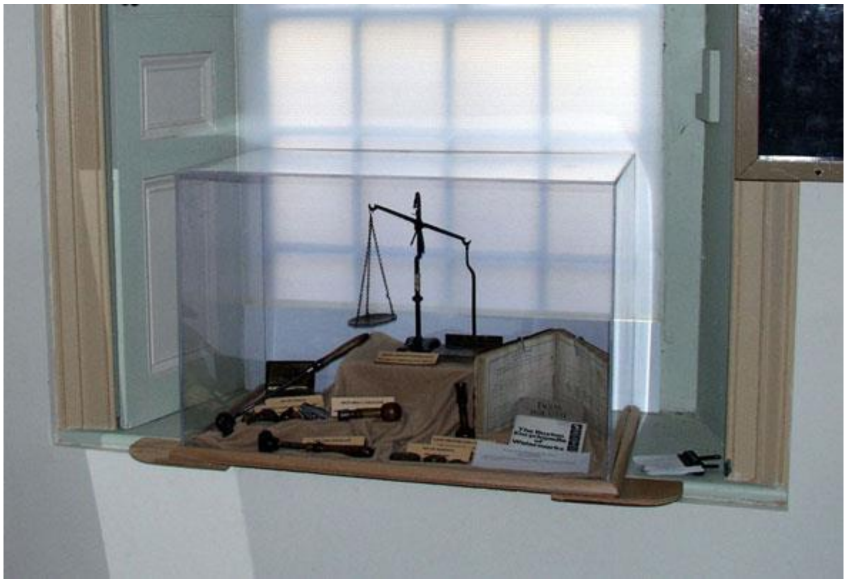

Figure 5: Use of a window well in a museum in a historic house. The window well is in a limestone building housing the Brockville Museum, Brockville, Ontario. Windows are notoriously tricky places to use with a mixed historic collections because the light is intense.

Here, two strategies have been taken: (1) The window has been screened by a translucent fluted plastic board, usually used for graphic signs. This reduces the light intensity by about one half (it also adds to the insulating quality of the window). This is a simple method using a few pushpins, easily removed if the room use changes. Although the glare from the translucent panel is less than ideal, the background fabric immediately adjacent to the objects is dark and matte. (2) Most importantly, zero sensitivity objects (metal stamps) have been selected for this display, or low-sensitivity artifacts (white paper, black ink, unstained wood). The brass stamps are very detailed, dark, low-contrast objects; therefore, seeing them well takes advantage of the strong window light.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Vignette 2: A local art gallery with basic track lighting

Figure 6: Track lighting in a small gallery.

Unlike the historic house with its original window wells described in the earlier vignette, a purpose-built display area, such as this small gallery at the Peel Regional Art Gallery, Brampton, Ontario, has full control of the lighting, both ambient and on the artworks. It uses a basic track pattern, one strip along each of the long walls, about 1.5 m from the wall, so that the light beam hits the painting centre at approximately 30° (to the vertical). The end walls are lit from the last portion of track. Note that glare control by the full lamp housings is very good when facing away from the viewer, but less successful when trying to light the left end wall. The spot lamps place the emphasis on the paintings and reduce competition from the walls, but finding spot lamps that yield moderate intensities at close quarters is difficult. Without knowing the artists' palettes, the gallery must assume some high-sensitivity colourants are in use. Because many of the artists selected for this gallery are local and alive, the museum could ask for information on the palettes, obtain their sensitivities, or even advise current artists about low-sensitivity palettes.

References

1. Colby, Karen M. "A Suggested Exhibition Policy for Works of Art on Paper. **Journal of the International Institute for Conservation-Canadian Group.** 17 (1992), pp. 3-11.
2. Michalski, S. "Damage to Museum Objects by Visible Radiation (Light) and Ultraviolet Radiation (UV)." In, **Lighting in Museums, Galleries and Historic Houses**. London: Museums Association, UKIC, and Group of Designers and Interpreters for Museums, 1987, pp. 3-16.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Key readings

1. Commission internationale de l'éclairage (CIE). **Control of Damage to Museum Objects by Optical Radiation**. CIE Technical Report, 157. Vienna: Commission internationale de l'éclairage, 2004.
2. Ashley-Smith, J., A. Derbyshire, and B. Pretzel. "The Continuing Development of a Practical Lighting Policy for Works of Art on Paper and Other Object Types at the Victoria and Albert Museum." ICOM Committee for Conservation. In, **Triennial meeting (13th), Rio de Janeiro, 22-27 September 2002: Preprints**. London: James & James, 2002, p. 3-8.
3. Michalski, S. "The Lighting Decision." In, **Fabric of an Exhibition, Preprints of Textile Symposium 97**. Ottawa: Canadian Conservation Institute, 1997, pp. 97-104.

Glossary

Blue Wool Scale

A scale for sensitivity to light fading based on a set of eight different dyed pieces of wool.

Foot candle

The Imperial unit of illuminance (light intensity) equal to one lumen per square foot or 10.76 lux.

Just noticeable fade

"Just noticeable" varies with observers, situations, and industrial conventions, but for practical purposes, it means more or less just what it says. Technically, it is defined here using the ISO convention of "GS4," the first full step on the scale of five paired grey squares used to measure fading during lightfastness testing. In other words, it is the change in colour that the industry considered represented "just noticeable" from a practical user's perspective. In colourimetric units, GS4 represents $\Delta E=1.8$. "Just noticeable" here must not be confused with the "just perceptible colour difference" that humans can see during optimal viewing circumstances, which is 2 to 6 times smaller than $\Delta E=1.8$, depending on colour. (Colorimetic systems such as ΔE (CIELAB) are an attempt, currently far from perfect, to find a metric that will have as its unit the "just perceptible difference" across the whole colour space.)

Lumen

The SI unit of luminous flux (light) used to rate the light output of lamps in manufacturer's catalogues.

Lux

The SI (metric) unit of illuminance (light intensity) defined as 1 lumen per square meter. Direct noon sunlight is almost 100,000 lux; 1 lux is about the intensity of light from a candle at 1 m (photometric units were originally defined literally in terms of a "standard candle" at one metre).

Mlx h

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Abbreviation of megalux-hour. A museum unit of light exposure, or light dose. Equal to the product of light intensity (lux) and time (hours), quantified in millions of lux hours. The use of the time unit hours is incorrect within SI rules, but this particular usage is common in museum conservation literature.

µW/lm

Abbreviation of microwatts per lumen. The museum unit of UV radiation. It is the ratio of UV intensity (in SI radiometric units $\mu W/m^2$) to light intensity (in SI photometric units, lux= $lumen/m^2$), hence the result µW/lm.

Thanks to the Centro Nacional de Conservación y Restauración in Chile, the Canadian Conservation Institute's web resource Agents of deterioration, translated into Spanish by ICCROM, is now available free of charge. Intended for curators and conservators, the resource identifies 10 primary threats specific to heritage environments.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Incorrect temperature

Stefan Michalski

Definition of incorrect temperature

Temperature, unlike fire, water, pests, etc., cannot be considered an agent of deterioration — we cannot speak of avoiding "temperature." From a collection risk and deterioration perspective, we must speak of incorrect temperatures.

Three practical categories of incorrect temperatures arise. Different collections have different sensitivities to each one.

- Temperature too high. This category can be subdivided into chemical, physical, and biological phenomena. The most important one for museums and archives is chemical: normal room temperatures are much too high for the long-term preservation of unstable human made materials, especially those carrying images, sound, and text. In fact, for most museums, only these archive collections require any thought about incorrect temperature.
- Temperature too low. Overall, low temperature is beneficial to collections, but polymeric materials, such as paints, become more brittle and fragile. Fortunately, careful handling mitigates most of the risk.
- Temperature fluctuation. This is the temperature issue that has most vexed museums and driven many requests for climate control (together with concern for fluctuations in relative humidity). This emphasis on temperature fluctuation has been out of all proportion to its significance for collection preservation.
- Although these three categories overlap in terms of control measures, it helps to keep them separate when assessing the risks to collections.

Occupants, energy, the environment, and sustainability

Temperature control in a museum raises issues of human comfort, energy cost, environmental impact, and sustainability. Conventional recommendations on museum temperature control emerged from a blend of human comfort needs, a limited amount of science, a considerable number of assumptions about possible damage from uncontrolled conditions, and an unfortunate tendency to generalize to a single rigid target. In a time of greater concern for the wise use of our planet's resources, such assumptions cannot be left unchallenged. For smaller museums that never achieved such control anyway, the question becomes, where should it focus its temperature control efforts, and why? This resource sketches out what we reliably know about the needs of collections, and where, typically, the large risks emerge.

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Deterioration by incorrect temperature, and the most vulnerable collections

Temperature too high

Cumulative chemical damage from all exposures to temperature that is high enough to cause rapid decay

Many products manufactured from the mid-19th century onwards, in particular paper, photographic materials, rubber, and many plastics, chemically self-destruct within a single human lifetime. To this list, we can add modern electronic records — from analogue tapes to digital discs. Table 1a and 1b lists museum and archive objects by their chemical sensitivity to a very important form of "temperature too high" — normal room temperature — and provides their approximate lifetimes. Because acid hydrolysis drives most of this decay, relative humidity (RH) plays a role as well (consult the section on [Incorrect relative humidity](#)), but temperature remains the most important factor to control. In addition to the materials that are acidic from the date of manufacture, we must add those materials such as textiles, paper, and leather that became acidic after exposure to certain internal or external pollutants, especially the sulfur dioxide of industrial air pollution of the 19th and 20th centuries.

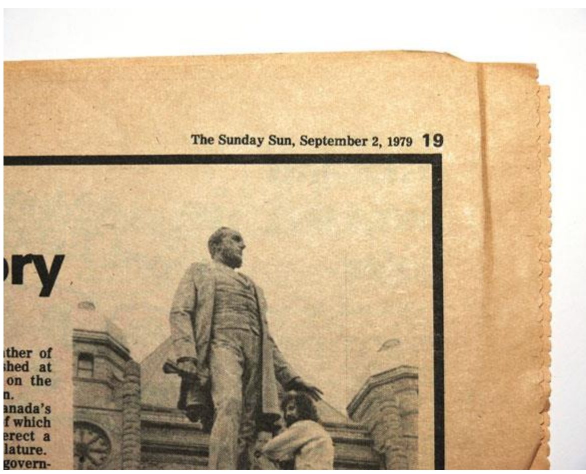

Figure 1. Examples of objects for which human comfort temperatures are "too high" for long-term preservation. When photographed, the newspaper was only 27 years old, and the rubber doll about 30 years old. Only cold storage can keep such objects well preserved for much more than one human generation.

An extreme example of high sensitivity is cellulose nitrate film and sheets (produced mainly from 1896 to 1952). These become powdery or sticky. Heavily deteriorated rolled films can even ignite above 38°C. Museums should identify these items and isolate them.

Table 1a and 1b. Chemical sensitivity of materials to room temperature and the lifetimes of the materials at various other conditions. All lifetimes are for ~50% RH. For the combined effect of RH and temperature on lifetimes, consult [Incorrect relative humidity](#). Sources for most materials are reviewed in Michalski (2000).

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Table 1a: Chemical sensitivity of materials to room temperature

Low sensitivity	Medium sensitivity	High sensitivity	Very high sensitivity
Wood, glue, linen, cotton, leather, rag paper, parchment, oil paint, egg tempera, watercolour media, and gesso. Serviceable examples of all these exist that are 1–3 millennia old from dry burial or dry enclosures at ~20°C. These examples were protected from any acid exposure, such as air pollution in the Industrial Revolution, and have never been damp. Skin, bone, and ivory of the wooly mammoth have survived intact for over 40 millennia while frozen.	Current best estimate for stable photographic materials to remain usable as images with little or no change, e.g. 19th century black-and-white negatives on glass, 20th century black-and-white negatives on polyester film.	Acidic paper and some film become brittle and brown, difficult to access, e.g. newsprint and low-quality books, papers, post- 1850 . Acetate film shrinks, image layer cracks. Celluloid and many early plastics, become yellow, crack, distort. Natural materials acidified by pollution (textiles, leather) weaken, may disintegrate.	So-called "unstable" materials. Typical magnetic media begins to be unplayable, e.g. tapes of video, audio, data; floppy discs. Least stable of the photographic materials decay, e.g. colour prints fade (in the dark), poorly processed items yellow, disintegrate; cellulose nitrate yellows, disintegrates, faster when packaged in large amounts. Many elastic polymers, from rubber to polyurethane foams, become brittle, or sticky, or disintegrate. Some acrylic paints on some canvas supports yellow rapidly.

Table 1b: Approximate lifetimes[1] of the materials at various temperatures

Temperature	Low sensitivity	Medium sensitivity	High sensitivity	Very high sensitivity
Heat treat, sun ~60°C	~4+	~1	~6 months	2 months
Hot room ~30°C	~250 years+	~75 years	~25 years	~7 years
Warm room ~25°C	~500 years+	~150 years	~50 years	~15 years
Normal room ~20°C	Millennia ~1,000 years+	A few centuries ~300 years	One human lifetime ~100 years	One human generation ~30 years
Cool store ~10°C	~5,000 years+	~1,500 years	~500 years	~150 years
Cold store ~0°C	20,000 years+	~6,000 years	~2,000 years	~600 years

1. Lifetime is defined here in terms of the effects or utility described for each material listed in the top row. Whereas the lifetimes expressed in each row have considerable uncertainty, the relative improvement from top to bottom rows is certain.

Note that the majority of materials in a mixed collection fall in the low-sensitivity category and have lasted centuries, even millennia, without "modern" care of their storage temperature. These materials have been preserved by a mix of moderate temperature conditions plus protection from industrial pollution, either due to a rural location or some form of enclosure, such as a building, a box, or the object's own structure, as in the binding that protects a closed book.

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A practical rule of thumb for the benefits of lower temperature states that each reduction of 5°C doubles the lifetime of the object (as can be seen in Table 1a and 1b when comparing steps of 5°C). There may be controversy over the criteria defining an object's "lifetime" — how much yellowing, distortion, or disintegration — but given a selected criteria, there is no doubt that the rule holds.

Physical damage during events when the temperature is too high

Some objects contain materials that will deform and weaken, or even melt, above a certain temperature. Table 2 lists some known temperature transitions and examples of the damage possible to objects. Aside from exotic examples of foods, cosmetics, wax, and the occasional problem of repair adhesives letting go, we can conclude that the most significant example in Table 2 is the irreversible distortion of modern plastic items. Many electronic media tolerate very little distortion before they become unreadable. An example from our daily lives is the rapid distortion of video cassettes, CDs, and DVDs when left in direct sunlight. Note that the temperature necessary for this rapid distortion, ~60°C, exceeds considerably what one might infer from the climate standards for such collections. Extreme caution always drives a large safety margin when writing standards, but from a risk-management perspective, it is useful to know what temperature exactly constitutes a collection catastrophe for short events (in this example, ~60°C for however many minutes or hours it takes each object to warm up).

The section on temperature fluctuations, below, addresses physical damage due to the expansion of materials caused by the rise in temperature itself.

Table 2: Physical damage caused by, or exacerbated by, temperatures too high and temperatures too low.

Temperature Range	Temperature (°C)	Physical effect and sensitive materials	Object examples
Too high	Above 60°C	"Heat distortion temperature" of many common plastics (PET, acrylic, HDPE, ABS, nylon in the 65–90°C range)	Plastic objects, plastic cassettes housing electronic media, optical media — all distort quickly and irreversibly at these temperatures.
	Above 60°C	Release of built-in stresses in biaxial PET that normally takes centuries, will occur over the course of hours to days.	The base of magnetic media, such as video, audio, or data tapes, floppy discs, deforms irreversibly. Records may become unreadable.
	Above 45°C	Melting or softening of waxes, e.g. paraffin wax 47–65°C, beeswax 60°C, carnauba 80°C.	Paintings: wax-resin-lined oil paintings may slide or detach from their lining. Encaustic paintings soften. Wax seals, candles, soaps, soften, deform irreversibly.
	Above 30°C	Mixtures based on waxy components deform, separate, form blooms. Chocolate melts (34°C). Various PVA glues soften significantly, lose strength.	Some foods and cosmetics deform, mixtures bloom, separate. Assemblies of paper, wood, repaired ceramics, using "white glues" can fall apart, especially if combined with high RH.

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Temperature Range	Temperature (°C)	Physical effect and sensitive materials	Object examples
Too low	Below 10°C	Ductile to brittle transition in carbon steels, varies widely with carbon content. (Aluminum and copper alloys have no such transition.)	The most famous cases were Second World War naval vessels cracking unexpectedly in the cold North Atlantic. Assuming no external loading, not an issue in museums. Operating or loading machinery in industrial collections more risky in winter than in summer.
	Below 5°C	Artists' acrylic paints, leathery and tough at room temperature, enter their glassy phase.	Acrylic paintings become more vulnerable to shocks and blows than at room temperature.
	Below -30°C	Artists' oil paints enter their glassy phase.	Oil paintings become much more vulnerable to shocks and blows than at room temperature.
	Below -40°C	Ductile to brittle transition in artists' acrylic paints. Many other practical polymers that are rubbery or leathery at room temperature will have become glassy, or even brittle, by -40°C. Shrinkage becomes significant; therefore, any restraint may cause fracture.	Acrylic paintings become extremely vulnerable to shocks and blows. Similarly, most rubbers and plastics that are elastic, or tough and leathery at room temperature, will be very vulnerable. Some plastic components may fracture if restrained, e.g. dial faces attached to wood or metal elements.

Biological damage during events when temperature is high enough for growth

Above ~4°C, mould becomes active. Above ~10°C (consult "Pests"), insects become active. Canadian collections rarely suffered mould or moths in winter when storage was unheated. Museums in cold climates must recognize that the decision to heat a collection dominated by wool, skin, or feathers, to human comfort levels, will not only cost more, it may also increase the mould and pest risks from a concern of six months of the year to a concern of 12 months of the year.

Temperature too low

"Temperatures too low" may cause physical damage. Many practical polymers designed to be tough at room temperature become stiff or even brittle as the temperature decreases, especially modern paints and coatings. Most of the risk to a collection is not that this change is itself damaging, but that the objects become much more fragile and likely to crack when handled. Table 2 summarizes the known phenomena. The change in brittleness is both sooner, and more dramatic, with acrylic paintings than with oil paintings.

Many ordinary objects in Canada have survived -30°C routinely. Common experience shows that most suffer no noticeable damage. (Consult Vignette 1). With the advent of low temperature "freezer" methods for non-toxic pest disinfestation in museums (consult "Pests"), many objects have been subjected suddenly to temperatures of -30 to -40°C. Recent controlled studies have reported only slight damage to a few items. It is currently unclear whether the damage was due directly to the low temperature, or to collateral effects discussed under fluctuations. Overall, the risks from low temperature to objects most at risk from pest damage, i.e. organic and generally tough or flexible materials, is much smaller than the risks from live pests.

Temperature fluctuations

Direct physical effect of temperature fluctuations

The sections on "temperature too high" and "temperature too low" discussed damage that can be attributed to a particular temperature, rather than the process of getting to that temperature from warmer or cooler conditions. In the case of physical damage, this was due to specific transitions in physical properties. This section on fluctuations considers damage caused by the change of temperature itself, regardless of where it starts or ends. This is the parameter the engineer and your mechanical systems are trying, expensively, to control when a narrow range of fluctuation is requested. The mechanism underlying the damage is the expansion of materials as their temperature climbs, and the converse, the shrinkage as it falls. There are two situations that lead to damage: when the components of a complex assembly have different coefficients of expansion, and when an object is subjected to a fluctuation more rapid than its ability to respond evenly.

These are classic engineering problems that have been solved for many complex objects undergoing extreme temperature fluctuations such as engines, long steel bridges, even glass coffee urns, etc. When one uses these models to estimate the risk of fracture, it is clear that the necessary temperature fluctuations to cause this form of damage in most objects in the size range between vehicles and hand-held objects is on the order of a minimum of ~200°C for brittle materials, and much higher for tough materials such as wood, paper, leather, and most paints. Damage due to transitions listed under temperature too high or too low, even charring, will occur before fracture. As noted under "temperature too low," recent studies of the side effects of low temperatures (-30 to -40°C) for pest control have found little to no evidence of physical damage. One researcher with long experience in the field (Padfield 2006) has observed only a single example of significant damage that can be assigned to the 50°C fluctuation itself, i.e. from 20 to -30°C and back. The damage was delamination of the metal layer from the glass of an old mirror. Thus, a laminate of very stiff, solid materials in a continuous layer, that had a weak bond (the silvering of aged mirrors is often easily peeled), provides a benchmark for high sensitivity to temperature fluctuations: it can survive decades of historic climate fluctuations (probably at least 15°C), but it is likely to delaminate if exposed to a 50°C fluctuation. This is consistent with the earlier estimate that most objects, especially those of more flexible materials than glass and metal (wood, paint, leather) or those with designs that allow relative movements (metal inlay in wood, watch and gauge faces held by clips) should tolerate the fluctuation of 50°C with very low or negligible risk.

What about many fluctuations? Repetitive stresses can give rise to fatigue cracking. Beginning with the "single cycle stress" that causes fracture, engineering data from many materials shows that at about one quarter of this stress for brittle materials (glass, ceramics, old oil paint) and one half of this stress for tough materials (wood, paper, leather), fatigue cracking will occur after about a million cycles. By about one eighth of this stress, fluctuations will be tolerated indefinitely, but because it will take 3,000 years to reach a million daily cycles and because most objects cannot respond fully to cycles faster than this, then we can take the million cycle/one quarter stress combination as a very cautious extrapolation of how much to worry about multiple fluctuations. Thus, we can extrapolate that if a high-sensitivity (brittle) object is damaged by one 50°C fluctuation, then daily fluctuations of 10°C will take many millennia to cause the same damage (hence the tolerance of prior history by the old mirror). For the great majority of archive and museum objects that are many times less sensitive, we can cautiously increase these permissible daily fluctuations to 20°C or even 40°C. The geological modelling on erosion of poorly bonded and brittle sandstone exposed to the temperature extremes of the desert for millennia suggests that this estimate is cautious because the day–night fluctuations experienced by such surfaces is well over ~50°C.

One author has reported that cracks in experimental paintings on canvas were due to small temperature fluctuations, but examination of the data shows that a combination of faulty temperature measurement and condensation on the canvas is a more likely explanation. The heavily cracked and cupped Krieghoff painting in Figure 4 in the section on Incorrect relative humidity, subjected to daily historic fluctuations in RH and temperature, shows an absence of cracks over the stretcher bars. Calculations of the thermal response, as well as the moisture response of the area over the stretcher bars (Michalski 1991), shows that this region was protected primarily from daily RH fluctuations, not daily temperature fluctuations. Therefore, the daily temperature fluctuations of a historic Canadian house do not appear to be responsible for the cracking in this object. On the other hand, some authors' computer modelling of old oil paintings suggests that low winter temperatures, as a seasonal fluctuation, are indeed responsible for certain patterns of cracks commonly observed.

Using the practical concept of "proofed fluctuation"

The analysis of the risks from temperature fluctuations is complex and many uncertainties remain. For practical purposes, one can draw instead on the concept of a "proofed fluctuation." Any object known to have been at least once at some very low temperature, say -30°C, or at least once at some high temperature, say 40°C, is not susceptible to further mechanical damage from one more event of the same magnitude because any fractures, delaminations, and irreversible compressions will have already taken place (unless the object is known to have weakened significantly from other causes in the interim). The fatigue effect does mean that one must modify this simplistic "proofed fluctuation" by noting that one should say that risks from single fluctuations should be predicted in light of the "proofed single fluctuation" and that the risk from repetitive fluctuations must be predicted in light of the "proofed repetitive fluctuations."

In other words, any future pattern of fluctuations that is similar to the past pattern of fluctuations cannot be expected to cause significant fluctuation damage. A practical corollary is that even modest improvements on past climate conditions will eliminate the risk of physical damage. It is important, therefore, to be accurate about assessing past climate control, and not to underestimate how bad it was because the worse one knows the past to have been, the easier it will be to make the future better. (The same is shown for RH fluctuations.)

Balancing the risks from conflicting "correct" temperatures

This variety of incorrect temperatures almost always means that one cannot find a "correct" temperature condition with zero risk to the collection, that one can only find the temperature conditions of minimum risk. The most common dilemma arises when considering cumulative chemical damage from "temperature too high," plus the mechanical damage from "temperature too low," plus the effects of the inevitable seasonal fluctuation. If, for example, a Canadian museum has a 20th century archives, a warehouse of newspapers, a collection of rubber dolls, the original rubber tires and plastics on its vehicles or agricultural equipment, and boxes of woollen textiles, should it take advantage of low winter temperatures, even if some materials may become brittle? Given that it cannot afford the machinery to maintain these cold conditions in the summer, will the large seasonal fluctuation outweigh the benefits of occasional cold? Is there a "compromise" that works best?

In short, yes, winter cold will help collection preservation in general. All the historical evidence we have comparing collections from different climates implies that the condition of our collections will be much better in the future if a collection goes cold every winter, and that any risks from the cold, or from the seasonal fluctuation, are either very small or non-existent.

A more nuanced approach to winter's benefits is possible. Once the winter temperature is below about 5°C, then the benefits of even lower winter temperatures are insignificant in terms of total annual chemical decay because the summer period of decay is unchanged. The mechanical risks, though, do continue to increase as the winter temperature drops below 5°C. Thus within a low-energy approach of a little winter heating and a little summer cooling, a "sweet spot" does exist in terms of total risks: keep summer below 25°C; keep winter above 5°C. To improve preservation of chemically unstable materials such as newspapers, film, tapes, plastics, etc., further than this, one must consider special year-round cold storage.

RH problems caused by fluctuating or uneven temperature

Museums and their consultants usually lump temperature and RH together under "climate control" or "the environment." Here we discuss incorrect temperature and incorrect RH as separate agents because both the damage to collections and the means of control are more dissimilar than similar, and because the entanglement of the two under "climate control standards" has led to many false generalizations and wasteful simplifications. For photographic and electronic records, for newsprint and office records, and for self-destructing plastic objects in modern art collections, the key issue is "temperature too high" with risks from RH fluctuations negligible in comparison. The complete reverse is true for collections of furniture, ivory, metals, and oil paintings — RH fluctuations are important while most forms of incorrect temperature are not. Furthermore, the low-cost, low-energy, passive solutions for each are distinct and become sidelined in the quest for a single engineering solution to "climate."

That being said, two practical linkages between fluctuating temperature and fluctuating RH must be noted. One is the problem of temperature fluctuations over time; the other is the problem of fluctuations over space, which can be more simply referred to as the problem of "uneven" temperature.

In a closed and empty room or display case at 20°C and 50% RH, with no humidity-buffering materials, a fluctuation of 1°C causes ~3% RH fluctuation. A fluctuation of 5°C causes ~15% RH fluctuation. The most dangerous fluctuation, a temperature drop over 10°C will cause 100% RH and condensation. Fortunately, for most spaces in most historic house museums, these effects are greatly moderated by the moisture buffering of the room or case surfaces. (The limitations on temperature fluctuations in the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE 2003) chapter specifications were determined more by this linkage to RH risks than by the temperature effects themselves).

Uneven temperatures from place-to-place in a building are generally a bigger problem than fluctuations over time, especially for museums in less than ideal buildings. The section on Incorrect relative humidity explains the various ways in which uneven temperatures become a source of incorrect RH. In short, the most important form of incorrect RH, damp is more often than not caused by humid air reaching localized cold spots.

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Sources of Incorrect Temperature

Sunlight

The single most damaging source of incorrect temperature is direct sunlight. Surface temperatures of dark insulating materials oriented towards the sun, such as dark wood, textiles, and plastics, can quickly reach 40°C above ambient air temperature; therefore, on a warm summer day, surfaces can reach 75°C. If these surfaces are enclosed by glass, as in display cases and picture frames, even higher temperatures are possible. Clearly, sunbeams have the power to exceed all temperatures listed as "too high" in Table 2, as well as making the rate of decay of all categories of sensitivity in Table 1a and 1b increase a hundred fold if routinely hit by a sunbeam. Paper sheets in glazed and backed frames are especially vulnerable because the RH needed for rapid decay is also maintained by the otherwise beneficial buffered enclosure.

Climate

Outdoor air temperatures in Canada range between the extremes of 40°C and -40°C. A change in the weather of 10°C usually takes many hours; a larger change usually takes many days. Outdoor air temperature is, thus, not a source of rapid fluctuations from the perspective of objects, nor a source of the severe high temperatures that can cause physical damage of Table 2. It is a source during summer of "temperatures too high" for unstable materials, but it is extremely benign to these same materials for the winter, and more so as one proceeds north. Some of the best-preserved samples of early movies have been found in the garbage in the high North because shipping them back at the time was not worthwhile.

Electric lighting

As does sunlight, incandescent electric lamps can cause surface heating due to their high content of infrared (IR) (this includes quartz-halogen lamps). Incandescent lamps have even higher ratios of IR to light than a sunbeam. After direct sunlight, excessive incandescent lamps used in display cases are probably the most common cause of extreme temperature fluctuations in museums (and the concurrent fluctuations in RH). The wide split in a rare First Nations saddle placed on display in the Museum of Man (Ottawa) during the 1970 s was almost certainly the result of not only low winter RH in the building, but also of even lower RH in the case caused by lamp heating.

Buildings and Their Climate Control Systems

Aside from whatever temperature the climate control system is delivering in the centre of the room on average, many forms of incorrect temperature will be located near local heaters and air vents. In rooms with poor or non-existent air circulation, exterior walls experience larger fluctuations than the room average, the ceilings are always warmer, and the floors always colder. Figures illustrating these zones of uneven temperature have been placed in the section on Incorrect relative humidity because the RH effects from these temperature differences are generally a bigger problem than the temperature differences themselves, especially when they cause damp.

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Objects in transit

Along with many other risks, the risk of incorrect temperatures is high during transit, especially for paintings. Temperature in uncontrolled vehicles in summer can be much hotter than the air outside. In winter, truck interior temperature falls well below the listed "temperature too low" values given in Table 2 for acrylic paintings. Even just a "quick run" between storage and display buildings in winter can cause lightly wrapped paintings to become much more brittle than staff expect, at the same time that the painting is flapping and bumping into walls and floors.

Control of incorrect temperature

Stages of control

Identify incorrect temperature values, and specify correct temperature values

Unlike other agents of deterioration (such as pests, pollutants, fire, etc.), where one wants none, or zero "agent," one cannot plan a goal of "zero temperature." One must determine the various incorrect temperatures before one knows what to control. Collecting large numbers of thermohygrograph records, and worrying whether the wiggly lines mean anything, is impossible without first assessing a collection's sensitivities (consult Tables 1 and 2). One thing is clear: humans are a very poor reference point. We like a temperature near 21°C, with no more than 2°C fluctuation if we are sitting. This setpoint is incorrect for most archival records and unstable modern plastics. The fluctuation limit is much more stringent, and resource wasteful, than needed for any collection.

Avoid

- Avoid placing organic objects, or fragile inorganic objects, in locations receiving direct sunlight. Even in outdoor storage of large objects, avoid areas with full sun exposure if the item contains wood, paint, leather, rubber, textiles, or plastics.
- Avoid creating sources of incorrect temperature during the design stage of purpose-made buildings. "Passive thermal control" amounts to making well-insulated walls, with high thermal mass, so that exterior temperature fluctuations are smoothed out over many days and weeks.
- Avoid selecting and installing mechanical systems that lack reliability and that cannot be easily maintained by local resources and local funding. Inform any consultants of this need. It is far more important to avoid a few extreme conditions due to system malfunction over the years, than to avoid routine small fluctuations from day to day.
- Avoid heating collections in winter that contain unstable materials, as noted in Table 2. Take advantage of the cold winter hiatus (if your region has one) from chemical decay and pest activity.

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Block

- Block sunlight, both by shutters and blinds for indoor areas, and by simple overhangs and roofs for outdoor items.
- Use insulation or at least provide an air space (10 cm or more) between objects and external walls, cold floors, and hot ceilings.
- Insulate artworks in transit, either in the crate, or at least with blankets if moving by hand a short distance outside.

Detect

- Monitor temperature. Of all the agents of deterioration, temperature is probably the simplest and cheapest to measure precisely.
- Detect signs of chemical damage, such as brown brittle paper and decaying photographs. These examples can be used as a general indication for decision makers unfamiliar with unstable materials. If you wish to establish that the temperature control in the recent past was especially incorrect, you will need accurate condition reports and good temperature records for the period in question.
- Detect signs of old mechanical damage, but interpret this carefully before drawing conclusions about current temperature control. Collection managers often point at cracked furniture or cracked paintings and cite them as proof that they need new climate systems. While this may (or may not) be true of the RH control, it is almost never proof that temperature control itself was inadequate.

Respond

- Respond via mechanical systems, such as heaters and air conditioners controlled by a thermostat. Reliability is essential.
- Respond to the issue of unstable materials that will disappear in one generation by lowering temperature, (or by other archive strategies, such as transferring the information to stable media).
- Segregate especially unstable materials in collections, such as badly processed negatives, pieces of urethane foam, and rubber items, mixed in with more stable materials. These often stand out visibly as sources of yellowing, and should be removed and stored separately (or discarded) because their degradation products damage adjacent materials.

Recover and treat

- Mechanical fracture can often be repaired, although disfiguring lines may remain.
- Physical deformations, from extreme forms of high temperature listed in Table 2, cannot be treated.
- Chemical aging, listed in Table 1a and 1b, cannot be treated.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Control strategies for different degrees of preservation

Basic control: No moving parts, no machinery, no energy consumption!

- Ensure reliable walls, roof, windows, and doors have good insulation, and preferably high mass walls.
- In addition to the above, ensure that direct sunlight does not strike any materials, especially those listed as sensitive in Table 2, which will suffer from a single day of direct sun. With these two steps in place, almost all physical risks from incorrect temperature are avoided, but high-sensitivity materials, listed in Table 1, will still have very short lifetimes.
- Inspect archival film collections and separate rapidly decaying negatives (due to poor processing) from the bulk of the collection. Segregate all cellulose nitrate films, to prevent acidic attack of adjacent materials, and to reduce fire risk.
- Inspect mixed historic collections and modern art collections, and remove any rapidly decaying nitrates, plastics, rubber, and urethanes that may contaminate adjacent objects.

Optimum control: Different collections, different situations, different control measures

- Follow basic control as above, plus integrate the following as needed:
- For archival collections and modern materials in mixed historic collections, identify the stability of the materials as listed in Table 1a and 1b, and provide cool or cold storage as required within the institution's mandate. Cold storage can range from a single-chest freezer storage (consult Vignette 2) to building-scale storage (see Wilhelm 1993). Groups of small museums should consider shared cold storage.
- For a mixed historic collection that has remained in an old building for many decades without noticeable change within the last decade, do not "improve" the control systems (e.g. add new components, or change their operation such as heating more in the winter than before), without carefully considering exactly what the current incorrect temperatures are and what evidence you have to believe they will cause more damage than the "improvements." Begin by ensuring the reliability and long-term maintenance of any current building elements and control systems, rather than changing the climate targets.
- When considering full-scale "building climate control," recognize the building envelope's limitations especially if it is of historic value itself. A table of five building types and their ability to tolerate climate controls is provided in ASHRAE (2003). For an overall philosophical approach to the dilemma, refer to the **New Orleans Charter for Joint Preservation of Historic Structures and Artifacts** of the Association for Preservation Technology International/American Institute for Conservation of Historic and Artistic Works (APT/AIC). Then select and implement an appropriate ASHRAE control set point and fluctuation level (ASHRAE 2003). (Consult Table 2 in the section Incorrect relative humidity.)
- When the objective is the display of travelling exhibitions, recognize that some major lending institutions require ASHRAE level A control, or sometimes AA (ASHRAE 2003). (Consult Table 2 in the section Incorrect relative humidity) and LINK TO CCI ASHRAE PAGE Purpose-built rooms or buildings are usually required. Consider a "room within a room" or cocoon approach (ASHRAE 2003).

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Conclusions

Not only are we poor judges of an object's response to temperature, but we also tend to personify the collection. It is difficult to feel that our most precious furniture or paintings are relatively content at a frigid -20°C, if left quietly alone. We ourselves much prefer to be heated in winter even if the result is a very low RH. We need to understand that our historic collections "feel" the opposite. They prefer to be cold accompanied by a moderate RH.

We also find it difficult to accept that the old materials found throughout most of humanity's history are quite stable, and that it is our own era's objects (late industrial through to the electronic era) that are the problem, that are as ephemeral as our own selves. While cold storage for us, or migration of our memories, may be a science fiction fantasy, they are the only practical solutions for much of our recent material heritage.

Traditional museum specifications for temperature were based not on any detailed consideration of collection needs, but on the superficial observation that collections did not seem so uncomfortable at the temperatures that we ourselves found comfortable. The fact that our human comfort temperatures appeared, conveniently, not to be incorrect for our collections, transformed into the notion that they were the correct temperature for our collections, which was not actually true for any known collection and completely false for many, such as libraries and archives. Permissible fluctuations, given the observations of bad things happening at very large fluctuations, were predicted to be very, very small, because less and less of a bad thing must be better and better. Unfortunately, such flawed logic has led us to greatly overrate temperature stability as a guiding principle, to spend unnecessary resources on its achievement, to gut the fabric of historic buildings in its implementation, and to use scarce energy resources fighting the benefits of cold winters.

Museums and their advisors adopted these standards throughout the world. Most still insist on very stable temperatures for collections, whether in storage or on display. It will take time to develop the consensus necessary to revise these standards, and, until such time, museums that want to receive travelling exhibitions or obtain various forms of museum accreditation will need to conform. Small museums caring rationally for their own collections, however, can begin to apply a risk-management approach and to use a more subtle and cost-effective logic than most standards allow.

Currently, the only published temperature (and RH) specifications for libraries, museums, and archives that follow this complex and graduated risk approach, that note explicitly that set points near 20°C are not beneficial for unstable modern materials, that provide suggestions for seasonal energy-saving adjustments, and that provide an estimate of overall risk from six different fluctuation specifications, is the current edition of the ASHRAE (2003) handbook. These specifications are provided as Table 2 in the section Incorrect relative humidity and are explained in further detail in a special page devoted to the ASHRAE specifications.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Vignettes

Vignette 1. Letting collections freeze and fluctuate in the yukon

Over 20 years ago, Michael Gates, Curator for Klondike National Historic Sites in Dawson City, Parks Canada, established a small, humidistatically controlled collection storage room. The electric heaters switch on when the RH climbs above 50%, and switch off below 50% RH. The result in winter is stable RH, and temperatures fluctuating in a range well below freezing, as low as -40°C. Energy use is very low. He has monitored the mixed collection of objects and not noticed any damage due to the low temperatures or the fluctuations. Note that the term "freezing," while loosely used in everyday language to mean temperatures below 0°C, does not mean that objects or their moisture content (at 50% RH) solidify. It is only liquid water that freezes at 0°C.

Vignette 2: Small-scale cold storage for archival records

The British Columbia Archives, now part of the Royal British Columbia Museum, established a modest cost approach to cold storage of its film collections by using a series of stand-up freezers. In order to provide very stable RH control, the items are individually packed using the double-bagging system of McCormick–Goodhart. (A single bag is enough to eliminate any risk of RH damage during freezer failure.) Although the museum finds that a large number of separate, and now ageing freezers, is becoming a significant maintenance issue (and may be replaced by a single walk-in facility), one or two freezers, as used by homeowners, has proven a very effective solution for smaller North American archives and museums.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Vignette 3. Video

Monitoring your environment - This video was created by the Canadian Conservation Institute.

References

- APT/AIC (Association for Preservation Technology International/American Institute for Conservation of Historic and Artistic Works). New Orleans Charter for Joint Preservation of Historic Structures and Artifacts.
- Michalski, S. "Paintings, Their Response to Temperature, Relative Humidity, Shock and Vibration." In, M. Mecklenburg, ed., **Works of Art in Transit**. Washington, D.C.: National Gallery, 1991, pp. 223–248.
- Padfield, T. Personal communication, 2006 .
- Wilhelm, Henry Gilmer, and Carol Brower. **The Permanence and Care of Color Photographs: Traditional and Digital Color Prints, Color Negatives, Slides, and Motion Pictures**. Iowa: Preservation Publishing Co., 1993.

Key readings

- American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). "Museums, libraries and archives." In, **2003 ASHRAE Handbook: Heating, Ventilating, and Air-conditioning Applications, SI edition.** Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2003 , pp. 21.1–21.16. (Note, the 1999 edition does contain the same temperature and RH specifications, but lacks the 2003 revisions on pollution. Pre- 1999 editions do not contain a "Libraries, Archives and Museums" chapter. New

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

editions appear every three to four years. Museums should expect consultants to use the latest edition.)

- Michalski, S. **Guidelines for Humidity and Temperature for Canadian Archives**. CCI Technical Bulletin 23. Ottawa: Canadian Conservation Institute, 2000.

Glossary of terms

Coefficient of thermal expansion

The fractional increase in length of a material due to a rise of one degree in temperature. Consult Michalski (1991) for a review of some values and sources.

K, k

Symbol for degrees Kelvin, the metric unit of temperature used by scientists, where 0 K is absolute zero. The convention for degrees Kelvin does not use the degree symbol. Each change of 1 K is the same as a change of 1°C. One can substitute 5°C for 5 K. Freezing point of water is 0°C or 273.15 K. Although European and Canadian engineers tend to use °C, the SI edition of the handbook, used by engineers in the United States (ASHRAE 2003), uses a mixture of °C for set point specifications and K for fluctuation specifications.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Figure 2. Betty Walsh, archives conservator at the **Royal British Columbia Museum**, beside the series of stand-up freezers used over the last decade for photographic storage. Inset, the double bagging system used for humidity control.

Thanks to the Centro Nacional de Conservación y Restauración in Chile, the Canadian Conservation Institute's web resource Agents of deterioration, translated into Spanish by ICCROM, is now available free of charge. Intended for curators and conservators, the resource identifies 10 primary threats specific to heritage environments.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Incorrect relative humidity

Stefan Michalski

Definition

Why "incorrect" relative humidity?

Relative humidity, unlike fire, water, pests, etc., cannot be considered an agent of deterioration – we cannot speak of avoiding relative humidity (RH) – but we can avoid "incorrect" relative humidity. From a practical risk assessment perspective, the many forms of incorrect RH can be subdivided into four types:

- Damp, over 75% RH.
- RH above or below a critical value for that object.
- RH above 0%.
- RH fluctuations.

Each of these will be explained in detail under "Deterioration". Different collections have different sensitivities to each of the four types, a few to only one, most to a mixture of two or more. Part of the difficulty in finding a "correct" RH for a collection, or a museum building, is the fact that a perfectly correct RH value may not exist for the collections. The best one can hope for is to find whatever range of RH causes the least amount of damage to the collection. Fortunately, for the majority of mixed museum collections this minimum damage rate is often very low, even zero, and the range of RH that yields this minimum damage is much wider than museums have assumed in the past.

Figure 1. Image of an old horse-drawn carriage. Mould and rapid corrosion caused by damp. A thin blue green layer of mould on the leather seats, and deep rusting of all the iron components, is typical in a shed that is dry most of the year, but damp in spring and fall.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Figure 2. Crizzling of trade beads due to frequent periods of RH above their critical RH.

Figure 3. A raking light photograph that shows the cracking and cupping of a painting due to a century of daily RH fluctuations. (Krieghoff's Jam of Logs on the Little Shawinigan, Rideau House, Ottawa.) Note how the areas over the stretcher bars are not cracked, since the wood bars reduced daily fluctuations in the area of the painting above them, by virtue of their moisture buffering capacity, which can last about 1-2 days.

What is relative humidity (RH)?

Relative humidity is a measure of the thing we call "humidity" in everyday speech. It is that quality of the air that ranges between damp and dry. We don't actually perceive RH itself, we perceive the dampness or dryness of our bodies in reaction to ambient RH, or we perceive the effect on objects such as paper or cloth, which become damp or dry in response to the RH. Although we can feel the difference between these two extremes, for all practical purposes we will need to rely on instruments to tell us what the RH is in the museum. (Consult the glossary for the technical definition of RH).

The relation between RH and museum objects

The amount of moisture in organic collection materials such as wood, paper, paint, magnetic tapes, etc., and on the surface of inorganic materials such as stone and metals, can be predicted best by RH. Although engineers that consult on climate control systems may use other humidity parameters such as vapour pressure or dewpoint temperature (Consult the glossary), all the deterioration issues of collections that are linked to humidity, and all the specifications one can provide for consultants about caring for collections in terms of humidity, are best expressed using RH as the parameter.

The relation between RH and temperature

It is sufficient for most purposes here to know that when warm air is cooled, the RH climbs. This leads to problems of damp when warm humid air finds cool spots in a building. The converse is that when cold air is heated, the RH falls. This leads to low indoor RH in winter, and drives the need for humidifiers. A more detailed explanation of this relation can be found in vignette 1.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Deterioration by incorrect relative humidity, and the collections most vulnerable

Damp (over 75% RH)

Damp has been understood since ancient times. It remains a constant battle, especially in the historic buildings that so often house museums. Damp causes several types of deterioration – mould, rapid corrosion, and extreme forms of mechanical damage. Although the practical boundary for damp is given as 75% RH, the deterioration rates all climb rapidly with increasing RH, so any reduction below 100% RH is beneficial.

Damp causes mould, which disintegrates or discolours skin, leather (Figure 1), textiles, paper, basketry, and occasionally wood, paint, and glass. Table 1 summarizes the different sensitivities to mould.

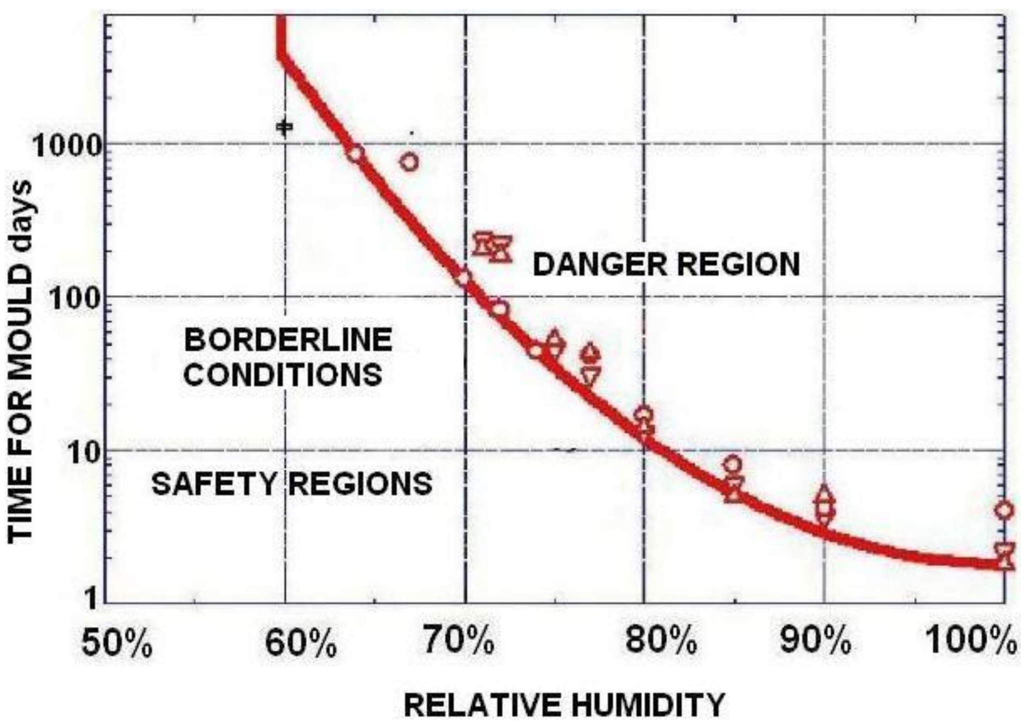

Figure 4. Time to onset of visible mould. Figure 4 plots the time before mould becomes visible. Theoretically, one can say the cause is mould spores, but since they fall on everything and just wait to grow, we must focus on the conditions that allow their growth – damp.

Table 1. A summary of all forms of deterioration due to incorrect RH, and the sensitivity of various collections to each one.
Incorrect Relative Humidity, Damp (75% RH - 100% RH)

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Effects	Low sensitivity		Medium sensitivity		Very high sensitivity
	None	**Years**	**~100 days**	**~10 days**	**~2 days**
Mould	**Inorganic artifacts** E.g., stone, metals, ceramics. If surface organic layer present such as dirt, may develop mould as listed at right, but effects usually superficial.	At 60% RH visible mould growth just possible on some surfaces, but a stable RH at this value is rare, any intermittent period at less than 55% will stop growth.	**Organic materials with a surface rich in soluble protein, starch, or sugar** E.g., leather, skin, parchment. Starched, sized, or dirty textiles and paper. 100 days at 70% RH… 10 days at 80% RH… 2 days at 90% - 100% RH **Clean plant based organic materials: mould rate typically requires 80% - 85% RH before mould growth likely at all.** E.g., clean textiles, clean paper, clean wood.		
Corrosion of metals	**Most precious metals.** E.g., gold and platinum. Silver unaffected if no tarnishing pollutants (sulfides) present but if pollutants are present, tarnishing rate will increase with damp.	**Coated or plated iron and copper alloys, but any coating flaws move to high sensitivity.** E,g. trophies, silverware, costume jewellery, vehicle trim. Metal tools, implements, instruments.	Lead, zinc, bismuth alloys (rate depends on presence of pollutants, such as organic acids). E.g., small Victorian castings, metal parts on many small consumer items, ship model elements.	Clean iron and copper alloys. E.g. tools, implements, kept bright and clean, but without coatings. Especially rapid if the artifact has mixed metals in contact.	Salt contaminated iron and copper alloys. Metal pitting and staining of adjacent porous materials takes weeks. E.g bright metals with fingerprints or cleaner deposits, archaeological and marine items, industrial machinery with road dust or salt deposits.
Colorants bleed	N/A	N/A	N/A	**Dyes bleed.** E.g. textile embroidery, watercolours on paper	
Special mechanical damage (beyond that considered under RH fluctuations)	N/A	N/A	**Glued wooden assemblies reform.** E.g. veneer buckles, due to a combination of cross grain veneer expansion and glue softening. When RH drops, the areas of veneer still in contact with the carcass adhere in an expanded state, and a portion of the buckle remains. Speed dependent on thickness of the wood and any coatings.		**Gelatin layers cement to adjacent surfaces.** E.g., stacked films and photographic prints "block", photographic prints buckle and cement to nearby glass frames. **Restrained, tightly woven textiles**

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Effects	Low sensitivity		Medium sensitivity		Very high sensitivity
	None	Years	~100 days	~10 days	~2 days
					shrink above 90% RH. E.g. paintings on canvas. Combined with size layer softening, paint layer tents, delaminates. **Paper and parchment cockle.**

Critical RH (critical RHs above 75% RH already noted under Damp, time to effects)

Effects	Low sensitivity		Medium sensitivity		Very high sensitivity
	None	Years	~100 days	~10 days	~2 days
Corrosion of metals	N/A	Disintegration of stable patina on old iron and copper alloys: several critical RH's between 20% RH and 75% RH, depending on metal/contaminant combinations. E.g. maritime and archaeological finds, "bronze disease."		N/A	N/A
Glass crizzling if below ~55% RH Weeping if above ~40% RH	Stable glass. E.g., most 19th-20th century pressed glass, lead crystal.	Unstable glass: loses luster, crizzles, may fragment. Stains, etches adjacent leather. E.g. some 18th-19th century glass bead work.	N/A	N/A	N/A
Minerals crumble, weep	N/A	A small fraction of minerals, such as hydrates and pyrites have specific critical RH above or below which they can crumble and or weep			

RH above 0% RH

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Effects	**Low sensitivity**		**Medium sensitivity**		**Very high sensitivity**
	None	**Years**			
Lifetime @ 50% RH, 20°C to Lifetime @ 10% RH, 20°C		**~300y to ~1500y**	**~100y to ~500y**	**~30y to ~150y**	**~10y to ~50y**
Internal chemical disintegration (by acid hydrolysis, dye instability, or residual chemicals).	N/A	Current best estimate for stable film materials to remain unchanged. E.g., old BW negatives on glass, new BW on polyester film.	**Acidic paper and some film become difficult to access.** E.g. newsprint and low quality books, papers, post 1850 brittle and brown. Acetate film shrinks, image layer cracks.	**Typical magnetic media begins to be unplayable.** E.g., tapes of video, audio, data; floppy discs. **Unstable photograph materials decay**. E.g., colour prints fade (in the dark).	**Worst samples of magnetic media begin to be unplayable.** E.g., tapes of video, audio, data; floppy discs. Some CD's.

Incorrect Relative Humidity, RH fluctuations

Effects	**Low sensitivity**	**Medium sensitivity**	**High sensitivity**	**Very high sensitivity**
±40% RH	None-small damage	Small-severe damage	Severe damage	Severe damage
±20% RH	None-tiny damage	None-small damage	Small-severe damage	Severe damage
±10% RH	No damage	None-tiny damage	None-small damage	Small-severe damage
±5% RH	No damage	No damage	None-tiny damage	None-small damage
Flat sheets of paper, film, tape, with an image or data layer may delaminate, fracture, or distort permanently.	**Support layer with finely dispersed image/data layers.** E.g., most single sheets of paper with print, halftones, line drawings, inks, washes. **Laminates with low differences in expansion.** E.g. most case-bound books. Most CDs. Commercial signs painted on metal.	**Layered structures with moderate strength, moderate differences in expansion.** E.g., most photographs, negatives and film. Most magnetic records. Thin, well adhered inks on parchment, such as deeds. Gouache on paper. Book bindings of vellum and or wood.	**Layered structures with poor strength, moderate to high differences in expansion.** E.g., Thick images on parchment. Globes. Thick oil-resin images on paper or cloth. Objects listed as medium vulnerability that have weakened substantially due to UV exposure, or aging already causing flaking.	**Large reactive (to fluctuations) sheets that are restrained at the periphery.** E.g., large paper sheets adhered to stretchers, 19th Century photo-portraits on fabric and stretchers. Large prints adhered at all four corners (usually tear near the point of restraint.)

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Effects	Low sensitivity	Medium sensitivity	High sensitivity	Very high sensitivity
Wood or wood assemblies may crack, split, delaminate, or distort permanently	**Single wood components, or assemblies designed to eliminate stresses, or.** E.g., floating panels in furniture or room paneling; tongue and groove planking nailed or bolted on edge only such as wainscotting, wood boxes on farm machinery (unless jammed due to painting, warping), hollowed out totem poles, wooden tool handles. **Assemblies with prior damage that allows stress release.** E.g. most old tables where all screws and joints are loose, any panels already split.	**Wood assemblies with uniformly distributed stresses during fluctuations.** E.g., most plain wood furniture with tight joints, no prior splits, most veneers and marquetry that cover a continuous piece below, such as most 18th Century - 19th Century chests of drawers, fine tables. Furniture made with plywoods, such as many Victorian catalog pieces. Note that fluctuation to higher RH may not always cause visible damage, since many joints, panels are invisibly crushed, but this makes them more likely to split during lower RH.	**Wood assemblies with concentration of stresses during fluctuations.** E.g., Veneer over corner joints, such as many wardrobe doors, Victorian secretaries, Art Deco furniture. Fretwork, applied wooden ornaments. Assemblies with bolts, nails, screws that hold both sides of a single plank. Many musical instruments.	**Wood assemblies with attached or inlaid metal, horn, shell, etc. that spans more than 1cm across the wood grain. Attachment or inlays may delaminate or buckle.** E.g. West coast masks with abalone, 18th Century-19th Century fine furniture, clocks, with inlays.
Paintings or paint layers may crack, delaminate, flake	**Acrylic paintings on canvas**. E.g., many paintings since 1960 . These may move to medium sensitivity if a heavy glue size was used, or if adhesion between layers is poor.	**Rigid paint layers on canvas, in moderate to good condition.** E.g. most oil paintings on canvas. These may move to high sensitivity if weakened by water damage, great age. Definitely move to high sensitivity if keyed too tight, or keyed flat during high RH. Note that fluctuation to lower RH is much higher	**Oil paint, gilding, on wide spans of wood, or paint on other organic rigid supports with weak adhesion.** E.g., most panel paintings, wide gilded panels. If the seams are flawed, with rigid fills, etc., then may become very high sensitivity. Miniatures on ivory, due to poor adhesion and undulations of some ivories. Heavy modern	**Paint layers bridging seams or flaws that concentrate stress.** E.g. polychromes, painted furniture, painted architectural wood elements. Note that hairline cracks over the joints of doors or painting frames are usually considered "normal" but not those in heavily

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Effects	Low sensitivity	Medium sensitivity	High sensitivity	Very high sensitivity
		risk to paintings than fluctuation to higher RH. **Oil paint, gilding on narrow spans of wood.** E.g. gilt furniture, picture frames.	paintings on smooth side of fiber-board may delaminate due to weak adhesion.	lacquered furniture.
Other organic objects	Woven organic materials without edge restraints. E.g. most basketry. Textiles such as blankets, flags, simple costumes.	High crimp woven organic materials with edge restraints may tear during fluctuation to high RH. E.g., needlepoint fixed to a stretcher, flat seat.	N/A	N/A

This page refers only to mechanical damage due to the fluctuation, and assumes a fluctuation long enough for the objects to completely respond. See other incorrect RH on the right page for concurrent additional effects. "Severe" means a high probability of noticeable damage with one fluctuation. "Small" usually needs careful inspection to notice the damage, "tiny" needs magnification. Since fracture can accumulate via fatigue, "severe" damage may be reached by several thousand cycles of "small" or several million cycles of "tiny." "Severe" does not usually mean loss of an archival record, unless it is a record for which dimensions are critical.

The largest fluctuation experienced by the object is the "proofed" fluctuation. Any fluctuation smaller than the proofed will cause much less new damage than indicated in this table or by the fatigue mechanism noted above. Most objects in Canada have experienced at least ±20% RH, many ±40% RH, so unless they have been repaired, their proofed fluctuation is typically at least ±20% RH. These are cautious estimates based on observations of collections, and currently available mechanical models.

Different museums experience very different mould histories, despite similar climate. Figure 4 explains most of these differences. Note how much the time for visible mould shortens in the RH range of 70% RH to 90% RH – from 100 days at 70% RH to two days at 90% RH. Note also that stable RH is not a good thing if it is a stable RH just within the danger zone of Figure 4. Far better for a collection stuck most of the time at 70% RH to have its RH fluctuate down to the safe zone every few days, since it will reset the mould growth clock back to zero.

Temperature plays a role as well in the onset of mould. Figure 4 holds for warm temperatures (~25 °C), so it represents a cautious generalization across all other temperatures. Graphs showing more detail on the role of temperature and RH in onset of mould are available in the key readings noted at the end of this section

Damp causes rapid corrosion of metals. The layer of water molecules that is always present on the surface of metals, grows rapidly above 75% RH. In addition, the ubiquitous contaminant from our hands, salt (NaCl), deliquesces (Glossary) above exactly 75% RH, and forms a very corrosive solution.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

RH above or below a specific critical value

Some minerals deliquesce above a certain RH, i.e., they form a salt solution by absorbing moisture from the air. For example, common table salt, sodium chloride (NaCl) deliquesces at 75% RH, and is widely used to melt ice on roads. Calcium chloride ($CaCl_2$) deliquesces at 33% RH, and is used in Canada and the US to control dust on roads, and by farmers as an anti-freeze for the ballast water in tractor tires (thus it can become widespread in agricultural collections.) Magnesium chloride ($MgCl_2$) deliquesces at 35% RH, and is found in sea water, and thus in the aerosols near the sea. If any of these salts have fallen on the surface of a metal object, especially iron and steel, the relatively harmless crystals change into an aggressively corroding salt solution above the critical RH.

In archaeological iron and bronze, a complex sequence of critical RH values, each due to a specific compound in the chain of corrosion, determines the rate of corrosion. In general for metals, the lower the RH the better, above 75% RH all corrosion speeds up a lot. If possible, avoid or remove any contaminating salt from these objects.

Unstable glass (such as the trade beads in Figure 2) "sweat" when the RH is above a critical RH (~55% RH) because fluxing compounds in the glass deliquesce, on the other hand they "crizzle" when the RH is below the critical RH (~40% RH) that causes dehydration of other compounds in the glass. The gap between these two critical RH forms the safe range for these unstable glasses.

A small fraction of minerals, such as hydrates and pyrites have specific critical RH above or below which they can crumble and or weep. For more information consult Waller (1992).

RH above 0% (when any water vapour is incorrect)

This may seem an odd definition for an incorrect RH, but it applies to all those archival materials such as acidic paper, magnetic tape, acetate and nitrate films, that decay chemically within a few decades – becoming weak, yellow, and brittle, or in some cases sticky (Figure 3). The chemical reaction behind this decay – acid hydrolysis – requires moisture, so the presence of any water vapour, any RH above 0%, permits the reaction to proceed. The rule of thumb is that the rate of decay can be cut by more than half each time the RH is halved. Table 1 summarizes the approximate lifetimes for various classes of objects at various RH (The section Pollutants discusses this process as well, since in this situation water vapour behaves like a pollutant).

RH fluctuations

Finally we come to the type of incorrect RH that has concerned museums more than any other – RH fluctuations. Although the physical phenomena that underlie damage from RH fluctuation are analogous to those discussed under fluctuations in the section on Incorrect temperature, the collections that are vulnerable are not at all the same.

A change in RH causes the moisture content of organic materials such as wood, paper, leather, photographs, negatives, plastics, paints, glues, etc. to change, which in turn causes their size to change. If the material is free to expand and contract as RH goes up and down, then there is no problem, but if the material is constrained by other components of the object, or simply by its own inner bulk during a rapid fluctuation, then expanding parts will be crushed, and shrinking parts may fracture (as with the paint in Figure 3).

A considerable amount of research on this subject has accumulated in the last two decades (Michalski 1993 , Erhardt 1994). Just as important, many conservators and collection managers with long experience of their collections have begun to share informally their observations and conclusions about the damage, or lack of damage, that they have seen over the decades. Taking all this information into account, Table 1 summarises our current best estimate of the likelihood of mechanical damage from various ranges of fluctuation (in the portion labeled "RH fluctuations").

Estimates for the fluctuation damage in Table 1 were derived by starting with what one actually sees in terms of fracture damage in collections that have experienced very low RH. In any cold climate zone, such as Canada, one can assume that heated and unhumidified buildings in the past experienced ~10% RH for sustained periods of time. The fact is, many classes of objects, such as paper bound books, wood handles, traditional wood doors, etc., survived very well, and the only physical damage present is clearly from poor handling. On the other hand, some things did crack, delaminate, or literally fall apart, e.g., barrels and wagon wheels. Some have even cracked audibly in their first winter in a heated museum (wooden folk art) while the collection manager sat quietly at their desk! Together with the current understanding of the science of these phenomena, we can generalize our observations across whole categories of objects. To a very great extent, the most important characteristic is not what specific material is in the object, but how it is assembled, and whether this assembly leads to constraint of some components.

What about many multiple fluctuations? Repetitive stresses can give rise to fatigue cracking Beginning with the "single cycle stress" that causes fracture, engineering data from many materials shows that at about one quarter of this stress for brittle materials (glass, ceramics, old oil paint) and one half of this stress for tough materials (wood, paper, leather) fatigue cracking will occur after about a million cycles. By about one eighth of this stress, fluctuations will be tolerated indefinitely, but since it will take 3,000 years to reach a million daily cycles (!), and since most objects cannot respond fully to cycles faster than this, then we can take the million cycle /one quarter stress combination as a very cautious extrapolation of how much to worry about multiple fluctuations.

The century old, heavily cracked and cupped Krieghoff painting experienced daily and seasonal fluctuations in RH and temperature – 30, 000 daily cycles, and ~100 seasonal cycles. It shows severe cracking, except in the bands over the stretcher bars. The wood of the stretcher bars can moderate the RH in their immediate vicinity for about 30 hours, no more, so they can eliminate the daily fluctuations in the painting layers nearby, but not the seasonal. Since the seasonal fluctuations are about the same, or larger, than the daily fluctuations, we can conclude that 30,000 cycles in RH are very much worse than 100 cycles, as expected.

If one is not convinced by this model of fluctuation damage and its predictions of risk, as in Table 1, one can draw instead upon the concept of a "proofed fluctuation". Any object known to have been at least once at some very low RH, say 10% RH, or at least once at some high RH, say 80% RH, is not susceptible to further mechanical damage from one more event of the same magnitude, since any fractures, delaminations and irreversible compressions will have already taken place (unless it is known to have weakened significantly from other causes in the interim). This is quite distinct from the other forms of incorrect RH, such as damp, or RH above zero, since mould and corrosion and acid hydrolysis do accumulate damage no matter how much has happened before. The fatigue effect does mean that one must modify a simplistic "proofed fluctuation" by noting that risks from a single fluctuation should be predicted in light of the "proofed single fluctuation" and that the risks from repetitive fluctuations should be predicted in light of the "proofed repetitive fluctuations." In other words, any future pattern of fluctuations that is similar to the past pattern of fluctuations cannot be expected to cause significant fluctuation damage. A practical corollary is that even modest improvements on past climate conditions will eliminate the risk of physical damage. It is important, therefore, to be accurate about assessing past climate control, and not to underestimate how bad it was, since the worse one knows the past to have been, the easier it will be to make the future better (the same is shown for temperature fluctuations).

A common question about RH fluctuations in small seasonal museums concerns winter operation: should I heat in the winter if I can't humidify? And if I need to open for occasional winter events, is gradual heating safer for furniture? The answer to both questions is "no." Winter heating causes RH to fall, as noted earlier under "The relation between RH and temperature." In many areas of Canada, by December, this can mean as low as 5% RH indoors when heating to 21°C without humidifying. This creates a high risk of the cracking of furniture (as in Table 1) but there is an important qualification: only if the low RH is maintained long enough for the furniture to fully respond. Most pieces of furniture take many days, even months, to respond fully, so one can reduce the risk from a limited period of low RH by keeping it as brief as possible, even if it necessitates an abrupt change.

Sources of incorrect relative humidity

Sources determined by the local climate

Wet weather obviously leads to problems of damp as illustrated in Figure 5. The converse is not true – a dry climate does not imply low RH, it only implies low precipitation. In dry climates such as the foothills of Alberta, daily average RH rarely falls below 35% RH, and is usually in the range of (40-70)% RH, as it is in most climates most days. Very low RH in Canadian museums only occurs with indoor heating. In summary, high RH problems are exacerbated by wet climates, and low RH problems are exacerbated by cold climates, since people like to heat indoors.

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Sources determined by site geography and building micro-climates

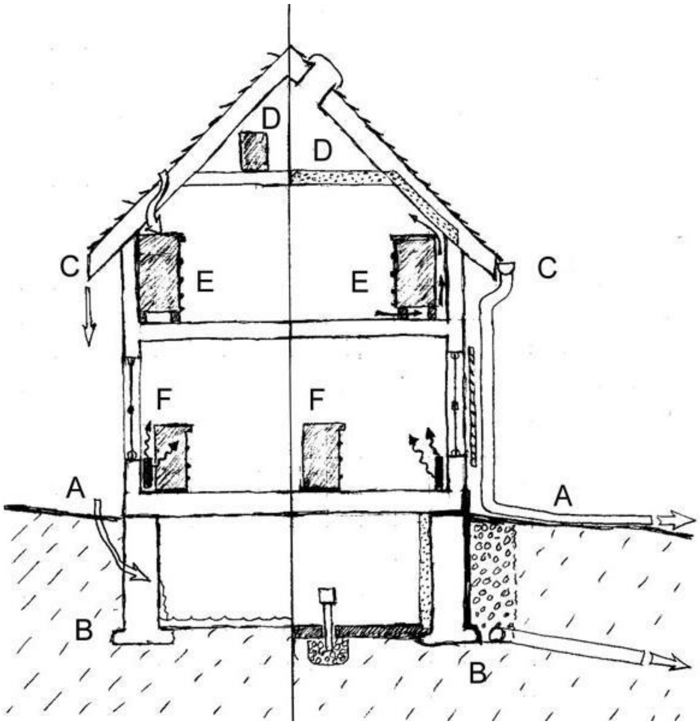

Figure 5. An image of a house that outlines common site and building scale RH problems, and their control. Poor surface drainage around the site, and poor soil drainage near the building, frequently cause damp inside small museums. Rainwater systems need to be in good repair, and new buildings built with a reliably sloped roof. Reducing the source of water is always preferable to using dehumidifiers to reduce the consequent damp inside.

- A: surface drainage;
- B: soil drainage;
- C: rainwater;
- D: hot attics;
- E: exterior walls;
- F: heating systems.

Because of space limitations, small museums often consider the basement as an option for collection storage, or even for display. Common experience teaches us that basements, or the ground floor of buildings with no basement, are associated with damp.

Museums also often use attics for museum storage. In poorly ventilated attics, summer sun causes very high temperatures, which in turn causes very low RH.

In rooms other than the basement or the attic, the most common problems occur near sources of heat (causing low RH), such as sunny windows or perimeter heaters, or sources of cold (causing high RH), such as exterior walls.

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In all such instances, if one suspects a possible source of incorrect RH, follow the procedures described under "Detect" in the section "Control of Incorrect RH."

Basements: Distinguishing rising damp from condensation on cold surfaces

There are two very distinct sources of damp in basements, with distinct means of control – rising damp, and cold surfaces. To distinguish the two, select a 30 cm square of the damp wall or floor, and wipe it dry. Place a 30 cm square piece of clinging plastic food wrap over the area, using tape or weights to hold the film edges down. Monitor the film until fogging or droplets form (a day or two). If the droplets are underneath the film, the problem is rising damp, and a source of external water needs locating and solving. If the droplets are on top, the problem is warm humid air entering the basement and forming condensation on the wall.

Sources determined by the micro-climates of portable fittings

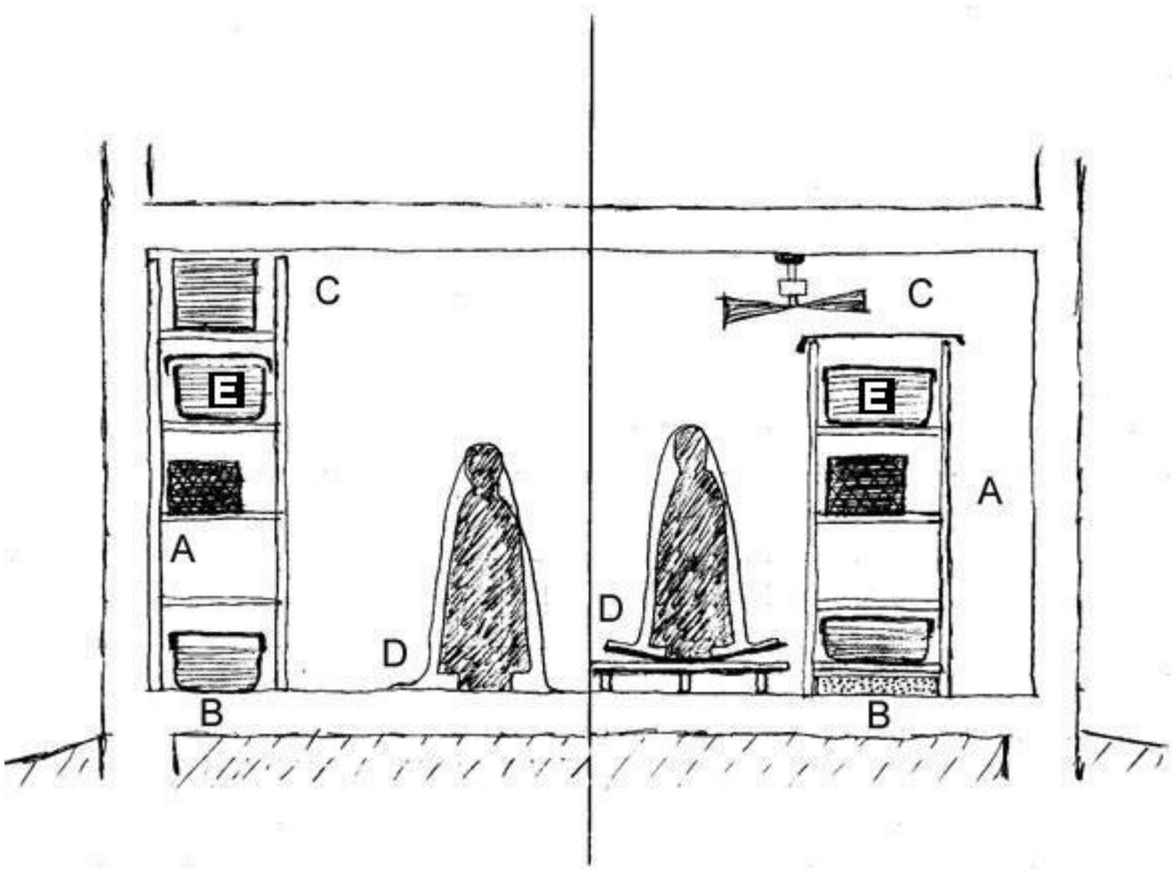

Figure 6. Portable exhibit and storage fittings generate incorrect RH in two ways: by their interaction with the room microclimate, and with their own internal microclimates. Figure 6 illustrates common examples, and their control.

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- A: fittings placed near exterior walls;
- B: fittings placed near cold damp floors;
- C: fittings placed near hot dry ceiling;
- D: dust cover draped over damp floor;
- E: semi-airtight packaging.

Shelving or cabinets placed against exterior walls suffer high RH during cold weather. Objects that are themselves good insulators, such as rolled textiles, costumes, suffer the most. Shelving and cabinets aggravate the problem of high RH near cold floors even more, since cold air sinks. Cabinets placed against south facing windows may protect the objects from sunlight, but the result is a heated, very low RH interior.

If the floor is concrete on ground, or a wooden floor above a dirt crawl space, it may be a source of rising damp. When museums use plastic dust covers over such sources of damp, or if the floor is prone to occasional puddles, then the plastic wrap will trap the damp, and exacerbate the problem. Check the floor for rising damp as noted earlier.

In all such instances, if one suspects a possible source of incorrect RH, follow the procedures described under "Detect" in the section "Control of Incorrect RH."

Sources determined by the micro-climates of packaging

Moisture-proof packaging benefits almost all collections in almost all situations, not only blocking damp and RH fluctuations, but also blocking pollutants, insects, and many physical forces.

Occasionally, however, packages become sources of damp, or aggravate damp from outside. Three problems arise: placing objects that are damp in the package, placing packaged objects in a situation of uneven temperatures, and placing packaged objects in areas that alternate between dry and damp conditions.

Packaging damp objects can happen inadvertently – packaging on a day when the room RH goes unusually high, or shortly after wet cleaning textiles. These objects will remain damp far longer than if they had been left open.

Uneven temperature across a package leads to damp, even condensation, at the end that is consistently colder than most of the package. This occurs whenever an uninsulated package is placed against a cold wall, whether in a room, truck, or airplane. It can occur whenever part of a package is heated by a sunbeam. It also occurs whenever packages are subjected to very sudden and extreme temperature drops, as in low temperature pest control.

In areas where very damp conditions alternate with dry conditions, whether daily, seasonally, or both, packaging will eliminate the daily fluctuations and reduce the seasonal fluctuations. The package RH will follow some slowly shifting average of the room RH. Whether or not the package interior remains in the safe zone (Figure 4) will depend on many factors: the exact vulnerability of the objects materials, the tightness of the bag, the buffering capacity of the object, and the ratio of damp to dry periods. Prediction, even when possible, is impractical and unreliable – one must either control the periods of room damp, or if that is not possible, monitor the package contents.

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In summary, if in doubt as to whether the package microclimate enters the danger zone of Figure 4, whatever the cause, and whatever the possible solutions, one must first measure the RH inside the package RH, as described under "Detect" in the next section.

Control of incorrect relative humidity

Identifying incorrect RH values, and specifying correct RH values

Unlike other agents that we recognize easily, and for which we just want "none", the various types of incorrect RH need identification before we can speak sensibly of control. This can be achieved by considering Table 1, and the section on deterioration. On the other hand, by the time we reach the respond stage, which includes building and running all kinds of active and passive climate control systems, the designers of such systems need a "correct" RH. Table 2 provides some examples of correct RH for collections in terms of the two design parameters: "setpoint" and "permissible fluctuation". Five levels of RH fluctuation are specified: AA, A, B, C, D, and the risks to mixed collections summarized. Note that in Table 2 a correct RH for a mixed collection does not reduce all forms of incorrect RH, it is at best a compromise between conflicting issues, and the residual risks are noted in the far right column.

In the long term, especially for small museums, thinking about RH control is best approached from the perspective of risk management that is, being aware of the most damaging kinds of incorrect RH for your collections, and focusing on their reduction (consult "Risk management.").

Table 2. Temperature and relative humidity specifications for mechanical control systems in museum buildings, showing their risks and benefits to various collections.

Collection Type	Setpoint or Annual Average	Maximum Fluctuations and Gradients in Controlled Spaces			Collection Risks/Benefits
		Class of control	Short[1] fluctuations plus space gradients	Seasonal adjust-ments in system setpoint	
GENERAL MUSEUMS, ART GALLERIES, LIBRARIES AND ARCHIVES: all reading and retrieval rooms, rooms for storage of chemically stable collections, especially if mechanically medium to high vulnerability.	50% RH (or historic annual average for permanent collections) T: A value between 15°C and 25°C (Note that rooms intended for loan exhibitions must be capable of the setpoint specified in any loan	AA Precision control, no seasonal changes	±5% RH ±2°C	RH: no change up 5°C; down 5°C	No risk of mechanical damage to most objects and paintings. Some metals and minerals may degrade if 50% RH exceeds a critical RH. Chemically unstable objects unusable within decades.
		A Precision control, some	±5% RH ±2°C	up 10% RH, down 10% RH up 5°C;	Small risk of mechanical damage to high vulnerability objects, no mechanical

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Collection Type	Setpoint or Annual Average	Maximum Fluctuations and Gradients in Controlled Spaces			Collection Risks/Benefits
		Class of control	**Short[1] fluctuations plus space gradients**	**Seasonal adjust-ments in system setpoint**	
	agreement, typically 50% RH, 21°C, but sometimes 55% RH or 60% RH).	gradients or seasonal changes, not both		down 10°C	risk to most objects, paintings, photographs, and books. Chemically unstable objects unusable within decades.
			±10% RH ±2°C	RH: no change up 5°C; down 10°C	
		B Precision control, some gradients plus winter temp. setback	±10% RH ±5°C	up 10% , down 10% RH up 10°C, but not above 30°C down as low as necessary to maintain RH control	Moderate risk of mechanical damage to high vulnerability objects, tiny risk to most paintings, most photographs, some objects, some books and no risk to many objects and most books. Chemically unstable objects unusable within decades, less if routinely at 30°C, but cold winter periods will double life.
		C Prevent all high risk extremes.	Within range 25% RH to 75% RH year-round T rarely over 30°C, usually below 25°C		High risk of mechanical damage to high vulnerability objects, moderate risk to most paintings, most photographs, some objects, some books and tiny risk to many objects and most books. Chemically unstable objects unusable within decades, less if routinely at 30°C, but cold winter periods will double life.

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Collection Type	Setpoint or Annual Average	Maximum Fluctuations and Gradients in Controlled Spaces			Collection Risks/Benefits
		Class of control	Short[1] fluctuations plus space gradients	Seasonal adjust-ments in system setpoint	
		D Prevent damp.	Reliably below 75% RH		High risk of sudden or cumulative mechanical damage to most objects and paintings due to low humidity fracture, but high humidity delamination and deformations, especially in veneers, paintings, paper and photographs will be avoided. Mould growth and rapid corrosion avoided. Chemically unstable objects unusable within decades, less if routinely at 30°C, but cold winter periods will double life.
ARCHIVES LIBRARIES Storage of chemically unstable collections	Cold Store: -20°C 40% RH	±10% RH ±2°C			Chemically unstable objects usable for millennia. RH fluctuations under one month do not affect most properly packaged records at these temperatures. (Time out of storage becomes the lifetime determinant).
	Cool Store: 10°C 30% RH to 50% RH	(even if achieved only during winter setback, this is a net advantage to such collections, as long as damp is not incurred)			Chemically unstable objects usable for a century or more. Such books and papers tend to low mechanical vulnerability to fluctuations.
SPECIAL METAL COLLECTIONS	Dry room 0-30% RH	RH not to exceed some critical value, typically 30% RH			N/A

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Collection Type	Setpoint or Annual Average	Maximum Fluctuations and Gradients in Controlled Spaces			Collection Risks/Benefits
		Class of control	Short[1] fluctuations plus space gradients	Seasonal adjust-ments in system setpoint	

1. Short fluctuations means any fluctuation less than the seasonal adjustment. As noted in the text under "Response times", however, some fluctuations are too short to affect some objects, or enclosed objects.

Compiled by Michalski, S. Canadian Conservation Institute for use in the ASHRAE handbook, first published 1999, and in a subsequent edition in 2004, 2007 (ASHRAE, 2007).

Avoid

In existing buildings where large changes are not possible, avoid all the sources of incorrect RH outlined in the previous section, such as Figures 5 and 6. In planning new buildings or renovations, avoid the creation of any of such sources in the first place. Note that the forms of incorrect RH illustrated in Figures 5 and 6 are not necessarily incorrect for all collections, e.g., low RH near a heater is not a risk to a metal collections, it may even be beneficial if the metals are contaminated with salts. Only damp can be generalized as something one must almost always avoid in museums.

Block

At all scales – the building, fittings, and packages – a layer of polyethylene film provides an excellent barrier to both water vapour, and air that carries water vapour, at very low cost. Many building materials with a layer of varnish or paint also make effective barriers.

Blocking incorrect RH at the building scale is often the most effective long-term solution for whole collections, but many subtleties emerge in the control of moisture in buildings, and an adequate description of design principles is beyond the scope of this text. Lstiburek and Carmody (1996) provide an excellent text targeted at smaller buildings and the range of climates found in North America. Before entering this technical world, however, museum staff can certainly concentrate on blocking one of the most common sources of damp in small museums, rainwater and groundwater.

Blocking incorrect RH at the scale of storage cabinets, display cases, and packaging, is well within the scope of museum staff. It can be effectively summarized in two statements: block all the holes and cracks that allow air infiltration into an enclosure; and block any adjacent hot or cold surfaces that give rise to incorrect RH via uneven temperatures.

In detail, blocking air infiltration in cases and cabinets means keeping all holes smaller than anything easily visible, and all cracks smaller than the thickness of heavy paper. Blocking air infiltration in soft packaging like polyethylene bags means closing the package well enough that when squeezed slightly one can feel the resistance of the trapped air. Unfortunately, when taking advantage of tight enclosures to block incorrect RH and external pollutants, one must ensure that the enclosure materials themselves are not sources of pollutants (consult Pollutants).

Blocking hot or cold surfaces, i.e., blocking heat transfer, requires insulation. Some of the solutions in Figures 5 and 6 rely on thermal insulation such as foam slabs, but don't forget that the simplest insulation is just an air gap that allows air circulation, 20 cm or more. (One can think of this as avoidance or as blocking).

As with avoid, whenever block is used as a tactic, one must check the results from time to time by monitoring RH, i.e., "detect".

Detect

Although the general pattern of control follows the stages of avoid, block, detect, respond, and recover/treat, in practice one must often begin an assessment of a particular situation at the detect stage. This is particularly true of an agent that is impossible for us to perceive accurately, such as incorrect RH.

There are four points to bear in mind when trying to detect incorrect RH:

- RH measurement always requires some kind of device.
- RH tends to be very local. One must measure at many points in a space to detect all possible areas of incorrect RH.
- RH usually changes over time, and
- Incorrect RH is often a combination of a particular RH and a particular time period (as in mould growth).

Measuring RH precisely and accurately requires an instrument costing on the order of $100 or more, plus the accessories to do routine calibration (time-consuming but feasible by the average user). Low cost hygrometers found in hardware stores, or desktop weather stations, are unreliable. Many regional conservation organizations offer these instruments on loan, already calibrated, or offer advice on purchasing.

Fortunately, we can sense the worst form of incorrect RH, damp, without elaborate instrumentation. If the object or the surroundings feel damp or smell damp (mouldy) they usually are! Simple and accurate confirmation of damp conditions can be made with table salt, since it deliquesces at 75% RH precisely. A few grains of salt attached to clear sticky tape, placed in any suspicious areas, will become droplets after some hours of exposure to damp. Even if the RH returns below 75% and the salt dries before one views the strip, one can see that the crystals have lost their structure.

When monitoring a building or a room, instruments that record RH over time are most useful. Ideally, one uses several recording instruments, placed in locations expected to have different RH (but focused on where the collections sit, or will sit). Most of the types of incorrect RH depend on the pattern over time. If, for example, one measures a room over time and finds zones that hover near 80% RH for periods of ten days or more, then from Figure 4, those zones can be documented as at very high risk for mould.

When monitoring smaller display cases and cabinets, one is typically looking for incorrect RH of various kinds caused by uneven or fluctuating temperatures, or one is looking for the extent to which external RH fluctuations, daily or seasonal, enter the case. For the former situation, an instrument capable of temperature and RH reading is necessary, but the period of monitoring can be brief. For the latter

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situation, a temperature reading is not essential, but one must anticipate a long period of monitoring, preferably a full year. In this case, a simple dial hygrometer, read daily, may be the most cost-effective method.

When monitoring packages, in addition to the situations described above for cases and cabinets, one is typically looking for signs of damp from various causes. Enclosing a small dial hygrometer, small data logger, or even an RH colour indicator strip, for a period of one day, is sufficient to detect this incorrect RH. If one has concerns about a packaged collection stored in a room with frequent damp periods, then continual monitoring of many, or all bags, is necessary, and the colour indicators strips may be the only reasonable alternative (aside from fixing the room RH).

When monitoring the collection itself for signs of mechanical damage, great care must be taken in interpreting symptoms. Collection caretakers often point at cracked furniture and cite them as proof that they need a new climate control system. There are three possible flaws in this reasoning: the cracks may not imply anything about current RH control, on close inspection many show decades old dirt or even varnish inside; the cause of the incorrect RH could be a single operational error (someone set the thermostat too high during a winter opening); and finally, the object that has cracked cannot crack again if RH control continues to be the same as the past. Using the collection itself to detect subtle effects of incorrect RH over the long term requires excellent photographic records, and routine inspection of the collection against those records.

Respond

Response to the detection of incorrect RH has several forms. Active machinery – humidifiers and dehumidifiers – respond minute by minute via their humidistats. Engineering consultants and technical information are abundant for building wide systems, e.g. ASHRAE (2007). Special museum systems, such as humidistatically controlled heating, are available (Consult Vignette 3). Portable domestic humidifiers and dehumidifiers are widely understood, and cost-effective for small museums, although one must take care not to create a water risk with these devices.

Passive control systems, such as an air-tight display case with the humidity "buffer" silica gel (consult Tétreault and Bégin 2018) depend on the ability of the case contents and the buffer to release or take up moisture when incorrect RH leaks into the case. (This can be thought of as a variation on blocking as well). Articles on silica gel use for museums often do not emphasize enough the role of case air-tightness in the final performance of the system. The book in the case shown in the Vignette 2: Simple display boxes that reduce incorrect RH, needs no extra silica gel, if the acrylic box is visibly air-tight at the base. It will be well protected from all RH fluctuations, i.e., it will "buffer itself." If it is in a leaky box, such as one with a 1mm crack at the top and the bottom seams, then adding one of the recommended ratios of silica gel from the literature will make little difference, and cost much more than just repairing the crack. On the other hand, silica gel is essential when making passive control cases for metal objects requiring very low RH. A case as air-tight as one can manage, and silica gel equal to about 1/10 of the case height, is a good design starting point.

The final form of response to incorrect RH, and the most important, is human. This means the consideration of everything in this section, and informed decision-making by museum staff.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Recover/Treat

One cannot recover from most forms of incorrect RH. Most mould damage remains. Corroded metals lose their original surface. Archive records ageing quickly at high RH must be migrated before the information is lost forever. Only fracture of furniture, paintings, etc. from RH fluctuations can be "reversed," although clearly it is preferable to prevent it, and the repairs are far from perfect.

Control in terms of overall strategies and target values

Basic control: No moving parts, no machinery, no energy consumption!

- Ensure reliable walls, roof, windows, doors, with good vapor barriers. In new buildings, explore low energy designs, high thermal mass, high insulation, high airtightness, used by some recent museums and archives.
- Identify and eliminate sources of damp (Figures 5 and 6).
- Use bags, envelopes, or encapsulation on all objects vulnerable to any type of incorrect RH. Transparent polyethylene or polyester is the most reliable, such as food quality bags, e.g. "Zip-Loc" TM.
- Use simple cases on the most sensitive and valuable objects on display. Consult Vignette 2 "Simple display boxes that reduce incorrect RH."
- Use backing boards on all paintings (Consult Daly-Hartin 1993)

Measures such as these that require no moving parts must not be forgotten when jumping to the next level of control, which tends to be more dynamic, interventionist, and thus more vulnerable to errors and accidents. These basic measures will provide control that remains in place even when the power fails, staff change, or the museum cuts its budget.

Optimum control: Different collections, different situations, different control measures

Follow basic control as above, and integrate the following as needed:

- For a mixed historic collection that has remained in an old building for many decades without noticeable change in the last decade, do not "improve" the control systems, e.g. add new components, or change their operation, e.g., heat more in winter than before, without carefully considering exactly what are the current incorrect RH, and what evidence you have to believe they will cause more damage than the "improvements". Begin by ensuring the reliability and long-term maintenance of any current building and systems.
- Use humidistatically controlled heating where feasible. (Consult Vignette 3: A humidistatically controlled storage building.)

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

- For small quantities of especially sensitive and or valuable objects, use passive microenvironments, such as airtight display cases and storage cabinets, with additional buffers such as silica gel if necessary.
- When considering full scale "building climate control," recognize the building envelope's limitations, especially if it is of historic value itself. Begin with reference to the **New Orleans Charter for Joint Preservation of Historic Structures and Artifacts**. Assess collection requirements, then select and implement an appropriate ASHRAE control setpoint and fluctuation level. (Table 2).
- When the objective is the display of traveling exhibitions, recognize that some major lending institutions require ASHRAE level A control, or sometimes AA. Purpose built rooms or buildings are usually required. Consider a "room within a room" or cocoon approach, or if available, a dynamic buffering approach.

Conclusions

Thirty years of excellent RH control by mechanical systems at huge expense means little to overall preservation if at some point in those 30 years there was four weeks of exceptionally low RH in an unpackaged furniture collection, or two weeks of very high RH in a photo archive kept in permeable paper packages.

One might argue, after such an experience, if one was lucky, that the collection still looks OK, but that begs the question of why one tried so hard to control the conditions 99% of the time. Or one might argue that if the collections had been in impermeable packaging, the risk would have been successfully blocked. Again, why bother with the elaborate mechanical control?

We tend to assume that RH control means some kind of automatic system, but these systems fail eventually, or they simply never existed due to lack of funding. The most important form of response, in museums both large and small, is human. Staff must learn to recognize the various incorrect RH, and begin to assess the risks to the collections, using Table 1. Often, one will find that only a small and manageable part of the collections is at significant risk from incorrect RH.

Control begins with those items listed above in Basic Control. Most of the time, these make sense even before assessment. With the basics in place, the more complex selection of Optimal Control Strategies begins. If in the initial example, the photographic archive used airtight plastic enclosures, and the furniture was wrapped in heavy gauge polyethylene, then many weeks of very high or very low RH would no longer pose a significant risk: they would be blocked.

A hanging quilt on display on an exterior wall is a different problem: it is not at all at risk from winter dryness, but it is at risk of mildew if the museum is humidified and the wall is cold (unheard of in winters before modern climate control).

Thirty years ago, humidity control for Canadian collections seemed a combination of simple specifications and high, unsustainable costs. We have discovered that for many museums and the heritage buildings that house them, the reverse makes more sense – complex specifications but low, sustainable costs.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Vignette 1. The relation between RH, temperature, and object moisture content.

The maximum concentration of water vapour in air more or less doubles with each rise in temperature of ~10°C. For example, at ~30°C, the maximum amount of water vapour, i.e. 100% RH, is ~36 grams per cubic meter, whereas at 20°C it is only ~18 grams per cubic meter, at 10°C it is ~9 grams per cubic meter, at 0°C it is ~4 grams per cubic meter, and so on. Thus 50% RH means that the water vapour concentration half the maximum noted, e.g., ~9 grams per cubic meter at 20°C.

The winter heating problem arises because cold outdoor air, e.g., 0°C and 50% RH, contains only ~2gram of water vapour per cubic meter. From the point of view of an object at 0°C, what matters is the 50% RH: the object will contain the same moisture as it does at 50% RH in a room at 20°C. Wood and paper, for example, will contain ~80 grams of moisture per kilogram of material. The problem arises when this outdoor winter air with ~2 grams of moisture per cubic meter is heated inside a building to 20°C. Since this 2 grams is only 1/9 of the maximum value of 18 grams at 20°C, the result is ~11% RH in the heated room (unless humidifiers add more vapour). If outdoors is colder, or the room warmer, the RH drops even more.

The cold damp problem arises with the reverse situation – air that is cooled. Air at 50% RH, if cooled by 10°C, e.g., from 25°C to 15°C, will now be at 100% RH. Further cooling results in condensation on objects. In hot humid weather, outdoor air coming into contact with floors or walls just a few degrees cooler than the air outside will form damp.

Vignette 2. Simple display boxes that reduce incorrect RH

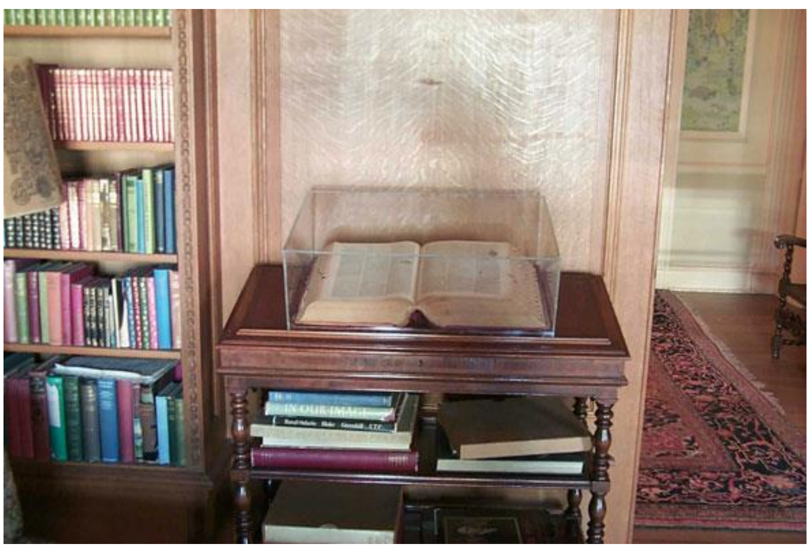

Figure 7. A simple display case for the most valuable book in a historic house collection. In the historic house at Parkwood the McLaughlin family bible rests safely inside a simple acrylic display case. There is no need for extra humidity buffer, the book itself has high moisture capacity. The RH inside the box will settle near the annual average RH, perhaps 40% RH, and fluctuate slowly between a range that is

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much reduced from the exterior fluctuations. The reduction of risk from summer periods of damp are the most important benefit to this object, since it is displayed open, thereby becoming much more vulnerable than when closed in normal use. Concurrently, the case also blocks airborne pollutants, insects, possibly UV, water, and contaminants from curious fingers.

Vignette 3. A humidistatically controlled storage building

The Prince Edward Island Heritage Foundation is responsible for several historic houses, each with storage needs for reserve collections that cannot be met by the houses. Many historic house museums suffer the same problem. When a recently built industrial building went on sale in the area, the group purchased it for collections' storage. Full climate control of the building would not have been possible without extensive modifications to the walls, but it was possible to consider humidistatically controlled heating. In this approach, the building system is switched on and off by a humidistat, rather than the thermostat. Heaters are switched on only if the humidity is above 50% RH. As the air warms up, RH falls, and when it reaches 50% RH, the heating is switched off. Full details are contained in the article by Lafontaine (1982). Periods of high humidity in summer are controlled by small portable dehumidifiers.

Figure 8. Interior of the humidistically controlled storage building, showing the oil furnace, and the controls on the column that switch it on and off so as to stabilize RH rather than temperature.

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Vignette 4. Video

Monitoring your environment - This video was created by the Canadian Conservation Institute

References

1. Daly Hartin, D. 1993 . Backing boards for paintings on canvas**. CCI Notes** Nº 10/10, (Canadian Conservation Institute: Ottawa).
2. Erhardt, D. and M. Mecklenburg. 1994 . "Relative Humidity Re-Examined," **in Preventive Conservation: Practice, Theory, and Research. Preprints of the Contributions to the Ottawa Congress, 12 - 16 September 1994** . IIC, (1994): 32-38.
3. Lafontaine, R. H. 1982 . "Humidistatically controlled heating: a new approach to relative humidity control in museums closed for the winter season" **Journal of the International Institute for Conservation, Canadian Group 7**. Issue Number: 1-2. 35-41.
4. Lstiburek, J. and J. Carmody. 1996 . **Moisture Control Handbook: Principles and Practices for Residential and Small Commercial Buildings.** (John Wiley & Sons, New York, NY).
5. J. Lstiburek is the leading expert in North American on moisture control in buildings, and the role of vapour barriers and air barriers.
6. Michalski, S. 1993 . "Relative Humidity In Museums, Galleries And Archives: Specification And Control." **In Bugs, Mold and Rot II: Moisture Specification and Control in Buildings**, edited by W. Rose and A. Tenwolde, National Institute of Building Sciences, Washington, DC, pp. 51-62.
7. New Orleans Charter.
8. Tétreault, J. and P. Bégin. *Silica Gel: Passive Control of Relative Humidity*, revised. Technical Bulletin 33. Ottawa, ON: Canadian Conservation Institute, 2018.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

9. Waller, R. "Temperature and humidity-sensitive mineralogical and petrological specimens" in **The care and conservation of geological material: minerals, rocks, meteorites, and lunar finds**, ed. Howie, Frank M. (Butterworth-Heinemann Publishers: Guildford) 1992 . pp. 25-50

Key Readings

1. ASHRAE. 2007 . "Museums, Galleries, Archives and Libraries (Chapter 21)", **2007 ASHRAE handbook: Heating, Ventilating, and Air-Conditioning Applications, SI edition** (American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. : Atlanta), pp. 21.1-21.16.
2. Michalski, S. *Guidelines for Humidity and Temperature for Canadian Archives*. Technical Bulletin 23. Ottawa, ON: Canadian Conservation Institute, 2000.

Glossary

Absolute humidity

A measure of humidity in terms of the weight of water vapour per unit volume of air. At 20°C, the absolute humidity of 100% RH is 17.3 g/m^3.

Deliquesce

The formation of a solution by certain salts that absorb moisture from the air above a critical RH value. E.g., table salt (NaCl) deliquesces at 75% RH and above.

Dewpoint

The temperature to which the air must be cooled to reach 100% RH. The dewpoint for air at 20°C and 50% RH is near 10°C. Often used by engineers to characterize the amount of water vapour in the air.

Hygrometer

Any device that measures RH. Not to be confused with hydrometer, a device to measure the density of a liquid.

Psychrometer

A type of hygrometer, consisting of two thermometers, one with a water soaked sock on its bulb (wet bulb) and one without (dry bulb).

Psychrometric chart

A graph widely used by engineers to plot the relationships between the vapour pressure of water in air, the air temperature, RH, and other parameters such as dewpoint. In the Key Readings identified there are psychrometric charts that include isoperms, i.e., lines of constant chemical lifetime of archival materials.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Relative humidity

The ratio of the partial water vapour pressure to the saturation water vapour pressure at the same temperature. Can also be expressed as the ratio of the concentration of water vapour to the saturation concentration of water vapour at the same temperature. Expressed as a percentage.

Vapour pressure

A measure of humidity in terms of the pressure exerted by the water vapour (which contributes to the overall air pressure). At sea level, 20°C, the contribution to air pressure due to the dry air is 101 Kilopascals (kPa), that due to the water vapour at 100% RH is 2.34 kPa (or 1.2 kPa near 50% RH).

Thanks to the Centro Nacional de Conservación y Restauración in Chile, the Canadian Conservation Institute's web resource Agents of deterioration, translated into Spanish by ICCROM, is now available free of charge. Intended for curators and conservators, the resource identifies 10 primary threats specific to heritage environments.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Dissociation

R. Robert Waller and Paisley S. Cato

Definition of dissociation

Dissociation results from the natural tendency for ordered systems to fall apart over time. Maintenance processes and other barriers to change are required to prevent this disintegration. Dissociation results in loss of objects, or object-related data, or the ability to retrieve or associate objects and data. It can manifest as:

- Rare and catastrophic single events resulting in extensive loss of data, objects, or object values;
- Sporadic and severe events occurring every few years or decades resulting in loss of data, objects, or object values; and
- Continual events or processes resulting in loss of data, objects, or object values.

This agent affects the legal, intellectual, and/or cultural aspects of an object as opposed to the other 10 agents of deterioration, which mainly affect the physical state of objects. This could be thought of as the metaphysical agent. Another unique characteristic of this agent is that loss in value to one or a few objects within a collection can reduce the value of the collection as a whole. Consider the effect of mixing objects between sample lots. Most large collections are assembled to support research and to serve as authoritative references. If a researcher, biologist, archaeologist, or historian observes a small but significant number of cross-contaminated sample lots, the collection as a whole is considered compromised. Thus, as a result of only a few cross-contaminated sample lots, a collection may lose much research and reference value.

Relation of dissociation to other agents

Continual physical force events or processes, such as abrasion, can contribute to eroding or detaching object labels. Pollutants and pests can degrade and damage labels, while incorrect levels of relative humidity can affect adhesives used to attach labels to objects. Rare or sporadic physical force events can result in mixing objects such that their connection to identifying information is lost. Similarly, fire and flood may damage or destroy labels or tags.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

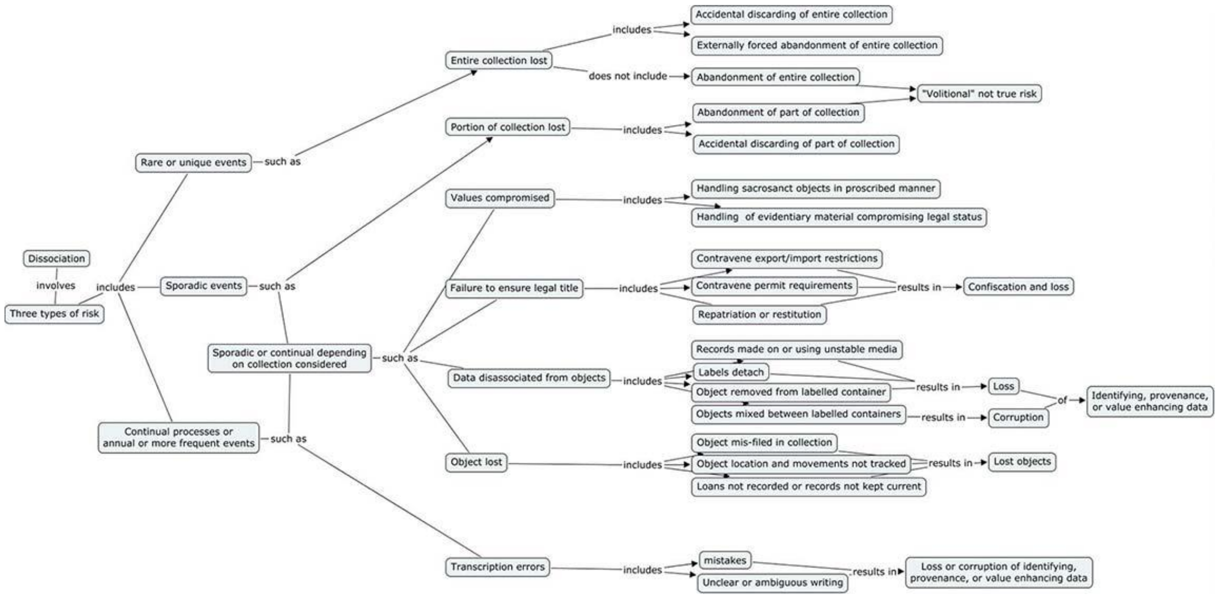

Figure 1. Specific risks of dissociation.
Dissociation involves three types of risk that includes: rare or unique events; sporadic events; and continual processes or annual or more frequent events.

Rare or unique events could result in the entire collection being lost; either by accident or by an external circumstance that forces the abandonment of the entire collection. "Abandonment" does not include intentional or "volitional" abandonment.

Sporadic events could result in a portion of a collection being lost either by abandonment (not intentional) or accidental discarding. Sporadic or continual events and processes that occur annually or more frequently could result in:

- values being compromised, leading to
  - Handling sacrosanct objects in proscribed manner
  - Handling of evidentiary material compromising legal status
- failure to ensure legal title, leading to
  - Contravention of export/import restrictions and permit requirements
  - Repatriation and restitution
    - which can result in confiscation and loss
- data being dissociated from objects, such as records made using unstable media, labels that become detached, objects removed from their labelled containers, or objects mixed between labelled containers; transcription errors including: mistakes and unclear or ambiguous writing leading to
  - Loss or corruption of identifying, provenance, or value enhancing data
- the object being lost, including:
  - mis-filing the object in the collection, not tracking object movements and locations, and not recording or keeping object loans current

Sporadic or continual risks due to theft and pilfering also result in displaced objects. Although in these cases objects are lost from instead of lost within a collection, the effects appear similar to misfiling in that objects cannot be located for use or inventory.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Origins of dissociation

Both actions and failures to act can contribute to dissociation-related risks. An example of an action causing dissociation is misplacing an object. An example of a failure to act is failure to document an outgoing loan.

Actions

Actions include any collection use activities that result in loss of objects, loss of data, or loss of object–data associations.

Examples include:

- Misplacing objects;
- Removing identifying labels or tags from objects;
- Recording object and collection data in an illegible or ambiguous manner;
- Recording object and collection data in nonpermanent manners; and
- Making errors in transcription.

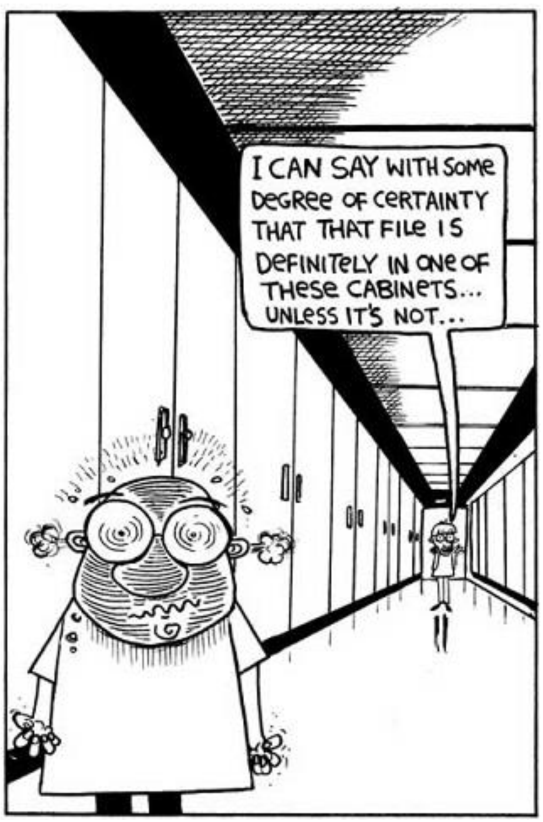

Figure 2. A misplaced object has lost virtually all value. © Canadian Museum of Nature

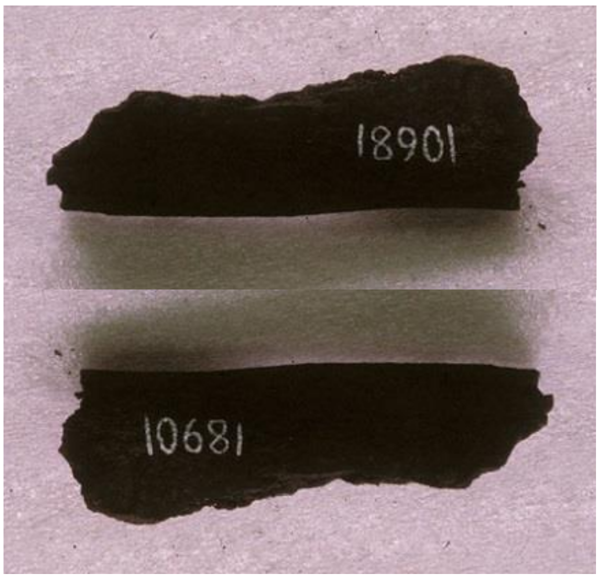

Figure 3. Two photographs showing the same object. First picture appears to be object number 18901, second picture appears to be object 10681. Photo by G. Fitzgerald. © Canadian Museum of Nature.

Other actions resulting in dissociation include handling an object or collection in a manner that is disrespectful of the value to certain stakeholders and, hence, results in loss of value to those stakeholders.

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Inappropriate contact with culturally sensitive objects is dealt with in Caring for Sacred and Culturally Sensitive Objects. Another example of this type of action leading to dissociation involves objects used as legal evidence. Evidentiary value must be preserved by protecting it from tampering.

Figure 4. Evidence tape can be used to seal packages such that tampering will be evident. Photo courtesy of Security and Safety Supply.

Using inappropriate products or procedures can lead to dissociation. Using nonpermanent inks to identify objects or using identification tags that wear to illegibility, crumble to dust due to the use of acidic papers, or become detached can all result in loss due to dissociation.

Failures to Act

Failures to act, such as neglecting to keep collection areas tidy, contribute to high dissociation risks. Failures to act can cause dissociation directly. For example, failure to migrate electronic data to new formats can lead to complete loss of the ability to access data. Failures to act include any situation in which:

- Legal requirements to ensure continued ownership are not adhered to;
- Collection-related data (especially electronic records) are not transcribed or migrated to ensure continued accessibility;
- Object identification is not permanent;
- Objects or collections are not adequately identified to prevent discarding;
- Objects are not tracked closely enough to prevent their becoming lost; and
- activities of maintenance staff are not proscribed enough to prevent accidental discarding or misplacement of objects or parts of objects.

Preventing failures to act requires establishing and maintaining adequate precautionary measures, including registration, tracking, inventory, and handling policies. It also requires an understanding of productivity pressures, including numbers of visitors, loans, and exhibits. Registration systems must be completely committed to so that they are respected in the face of extraordinary productivity pressures.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Effects of dissociation

The effects of dissociation include compromise or loss of objects, collections, and the data that give them value through context and meaning. The effect can seem slight, such as reducing the certainty that a single object is properly identified. Indeed, no collection is perfectly documented and all collections will have an error rate in identification. However, when an error rate becomes unacceptable to users of the collection, then the entire collection, and not just the objects directly affected, will lose value. This magnification effect, where compromising a few objects and/or their data affects the value of many or all objects, is an insidious aspect of the agent dissociation.

At the other extreme, the effect can be immediate and cause the complete loss of an entire collection and its documentation. This might occur when an organization, not understanding the value of a collection, decides to dispose of it. Collection material might be discarded simply because it is not adequately identified as part of a collection unit. Loss can happen by complete accident; for example, when movers mistake collection materials for other items designated for disposal (Vignette 1).

Complete loss can happen when a shift in purpose or orientation of a collection-holding organization results in management wishing to divest itself of collections through disposal. However, because this risk arises as the result of choice, it would be termed a volitional risk and not be subject to objective evaluation from the perspective of the organization itself. However, from the perspective of society as a whole, collection abandonment, for example, by government departments that change their focus, may represent substantial loss.

General outline of effects

The general outcomes of dissociation from any cause are loss of objects, of whole collections, of their associated data, or of their values. "Loss" is used here to mean "becoming unable to retrieve on demand that which is wanted." In the case of data loss, objects or collections lose context and information-related values. In the case of inappropriate use, spiritual, ritual, and other cultural values are lost.

High-sensitivity objects and collections

Numerous factors contribute to sensitivity to dissociation risks at both object and collection levels, as well as at both staff and management levels (Table 1).

Factors contributing to dissociation: Characteristics leading to increased risk of dissociation

Object

- Illegally acquired object
- Small object size (difficult to label)
- Fragile objects (difficult to label)
- High cultural value
- Unresolved copyright or ownership issues

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

- Object currently not "fashionable" (dated taxidermy specimens)
- Object valued for uses not common to bulk of collection (e.g. exhibit value in research collection)
- Object used for destructive sampling or destructive research

Collection

- Large numbers of objects
- High diversity of objects
- Collection data contributed from many diverse sources
- Tradition of illegal object acquisition
- Overall poor condition of collection
- Digital media susceptible to obsolescence

Collection care staff

- Unregulated or unrestricted access to collections
- Staff not aware of legal issues
- Choice of unstable products or poor systems for catalogs and labels
- Incomplete or inadequate record keeping
- Staff not adequately aware of storage organization
- Poor organization of the collection
- Other professionals' sense of collection values and issues not comprehended
- Cultural value not understood or appreciated by custodians
- Untrained volunteers not aware of correct procedures

Management of collection responsibility

- Collection not held in dedicated, appropriate spaces
- Collection care is secondary or tertiary responsibility of staff
- Insufficient, part-time, intermittent staff
- Staff not trained in collection management
- Priority for due diligence much lower than priority for product delivery
- Failure to foster appreciation of collection values

Control of dissociation

The control of dissociation relies heavily on effective policies and procedures (Vignette 2). In large institutions, establishing and implementing these policies and procedures are often the responsibility of a registrar or collection manager. In smaller museums, they may be implemented by whomever assumes responsibility for the collections, including managers, volunteers, and even students.

Dissociation risks are minimized through meticulous documentation of all transactions, uses, and movements of objects, and through systematic and correct implementation of procedures that link objects to data. This begins with ensuring that legal title to specimens is clear and transferred to the museum. Permits required to collect, obtain, or import objects must accompany the object. Steps involved in accessioning, or formally taking ownership of the object, must be clear and formally documented. Objects must then be securely linked to their accession record and any associated information, other parts, or

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

ancillary collections. This is generally done by assigning a unique identifying number (frequently a catalog number) and registering that number with identifying data in a ledger. Increasingly, computer databases hold the collection registration files. These files must be adequately maintained and updated as well as securely archived and regularly migrated to formats accessible to current computer systems. As well, staff must be trained in maintaining and retrieving this information, including methods for troubleshooting problems.

Equally important are the procedures to physically link the unique identifying number and related data with the object. Standard protocols are essential for:

- The method of labeling;
- The materials used for labels; and
- The sequence of temporary and permanent labels relative to the steps of preparing objects to be added to a collection, placed on exhibit, or sent out on loan.

If reasonable policies and procedures are in place, the critical factor in limiting the risk of dissociation is institutional and individual staff persistence in meeting a high level of documentation standards, despite productivity pressures.

In the case of digital archival collections, it is the entire collection and not only the collection data that is at risk. Especially at risk are digital collections that are not accessed frequently enough to ensure that any required reformatting is completed while the old format can still be accessed. For many institutions, linking the back up and reformatting of digital collection information with that of corporate electronic records management may be the most effective strategy for managing migration and back up.

Stages of control

Effective policies and procedures are the key to controlling dissociation risks. Furthermore, developing and implementing such efforts must involve periodic updating, training, and assessment to ensure quality control.

Avoid

As always, avoiding a risk is the preferred approach whenever possible. Always ensure that a clear title to objects is obtained before objects are acquisitioned. Label all objects or groups of objects with identifying numbers.

Block

Develop and implement policies and procedures to ensure adequate registration tracking of all object movements and assure standards of labelling are systematically and correctly applied.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Detect

Regularly scheduled inventories improve the probability of detecting symptoms of dissociation. In large collections, inventory of a sample or subunit of the collection is a viable alternative to a full inventory. Proofreading data after entry or migration is essential to detect transcription or migration errors.

Respond

Implement procedures for replacing faded or otherwise deteriorated labels, re-filing of used collection materials, and so on. Periodic training in procedures for volunteers, staff, and collection users also helps mitigate these risks. Data cleanup and reconciliation of inventory discrepancies are other examples of responses when dissociation problems are detected.

Recover

Maintain and use a system for documenting objects dissociated from their data and data dissociated from their objects. This will usually involve a registry of dissociated labels, catalog entries, and/or specimens that can be consulted to seek matches as new dissociated parts are discovered. A practice of asking collection users to bring dissociated objects to the attention of the collection manager will also help recover misfiled objects. For digital collections that have been rendered unusable due to an outdated format, arrangements for reformatting might be made.

Levels for control

Dissociation is primarily controlled at the policy and procedure level as well as at the object level.

Stringent adherence to procedures for acquiring, registering, and tracking objects is of utmost importance. Temptations to succumb to productivity pressures, such as allowing a loan to be sent or taken away without full documentation, cannot be tolerated. Requirements for documenting and tracking specimens are defined and maintained within the field of museum registration and have been well described by that area of specialization (consult Buck and Gilmore 1998).

Procedures to research the need for and the acquisition of permits for object loans or acquisition must be systematically applied. Many permit requirements apply to objects in cultural collections, as well as to natural history collections, because legal statutes apply to the movement or use of components or materials of objects (e.g. feathers, ivory), not only to the initial collecting of the animal.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Figure 5. Objects containing ivory or other natural materials for which trade is internationally regulated could be confiscated during international transit. Ivory Comb with human face, Late Dorset culture, Devon Island. Canadian Museum of Civilization, QdJb-3:69. IMG2012-S90-2660-Dm.

Buck and Gilmore (1998) provide descriptions of general permit requirements. Consult provincial, state, and federal agencies for current requirements (e.g. Convention on International Trade in Endangered Species of Wild Fauna and Flora; Cultural Property Import and Export Act (Canada); Canadian Cultural Property Export Control List).

At the object level, objects must be identified to enforce a link between the object and its associated data. That associated data will include acquisition files indicating proof of ownership; catalog files including provenance information and conservation documentation; research files including field notes and referrals in publications; and ancillary material such as molds, casts, photographs, radiographs, preparations for and results of analyses, and so on. In general, simple systems involving a unique number, together with an institution identification code are preferred to more complex systems with encoded information. Simpler systems tend to be more sustainable over long periods of institutional history.

Objects must be labelled (Vignette 3). Ideally, the catalog or registration number is physically associated with the object, usually by marking or labelling. In some cases that is not possible. For extremely small objects and those with very friable surfaces, direct marking of the object may not be practicable. In these cases, the catalogue number is marked on an attached label, on the (most unique) container holding the object(s), or on an integral part of the support for the object or object container system.

Application of numbers directly to objects has been the most common way of ensuring unique identity. The techniques for applying numbers are well established. Several publications deal with the subject in detail (see Canadian Conservation Institute 1994 a and b; Ogden 2004; and the Museum Documentation Association website). In general, "solid" materials, such as stone, metal, and wood, have a separating layer painted onto the object between the number and the surface. Alternative techniques are used on softer and more absorbent materials, such as paper, leather, and textiles. In addition to an object's material, texture, and structure, selection of a labelling method requires considering specimen use (exhibit, research, reference), facilities such as fume extraction, consistency within a collection or institution, and sometimes other issues.

Labels, either attached to objects or kept loose but in association with the object, may have historical or aesthetic value of their own. These labels warrant special consideration (Vignette 4).

Control strategies

Control strategies for different levels of intervention are available.

Summary

Dissociation results in loss of objects, object-related data, or the ability to retrieve or associate objects and data. The principal means of control against the risk of dissociation is establishing and complying with policies and procedures meant to document and control the acquisition and movements of objects. The ability to exercise professional discipline to abide with these policies and procedures through periods of great productivity pressures is often the risk-limiting factor for dissociation. Where appropriate and

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

adequate policies and procedures are not instituted and respected, dissociation will likely be the greatest risk to a collection.

Vignettes

Vignette 1. Accidental discards

Beauty is in the eye of the beholder

Without doubt, every collection of any significant size and age will have suffered incidents of accidental discarding of objects. This happens almost annually with contemporary installation art where sanitation workers will discard what appears to them to be something in need of disposal. The installation piece **Anna Dropped Her Basket** by Leslie Rech was cleared away the day after installation by a city "clean team."

Figure 6. "Anna Dropped Her Basket" by Leslie Rech. Installation art before being discarded.

Headline read "Canadian artifacts sent to garbage dump"

Accidental discarding is a real and ever present risk to all collections and no collection is completely immune. Rarely, but on occasion, accidental discarding can take on catastrophic proportions. In 2003, for example, workers mistook an entire Ontario Archaeological Society collection of 433,000 objects stored in 289 boxes as garbage for disposal.

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Figure 7. Toy bowl from Beeton Site, BaGw-1, ca. 1500 A.D. Catalog number 133-X1.12-463. One of 433,000 objects lost in the accidental discarding of a collection. Photograph by Ken Jones, reproduced courtesy of Marti Latta, University of Toronto.

The boxes were being stored in a corridor with an assortment of used equipment, but were segregated in a locked cage. A message advising of the impending clean up had circulated through management, but not been received by the curator responsible for the collection. Risk factors for this collection can be identified in Table 1. Note: check the section dealing with the management of collection responsibility.

Vignette 2. I'm not pulling your leg, sometimes stray objects are relocated!

"Missing leg found"

Since 1924, the Canadian Museum of Nature's (CMN) Vertebrate Zoology collections have included a mounted skeleton of a horse imported to Canada by the former Governor-General Prince Albert, Duke of Connaught. For an unknown reason, the horse lost a leg at some point and was thereafter referred to by staff as the "three-legged horse." During a teaching stint at Carleton University early in 2005, CMN paleontologist Natalia Rybczynski noticed that the university's Biology Department had a freestanding horse leg covered with white paint with holes for attaching wires. The vagrant leg proved to be the missing limb of the CMN's horse. It had probably ended up at Carleton some 30 years ago as part of an improperly documented loan. With permission from the Biology Department, the stray leg was reunited with its rightful owner.

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Figure 8. Three legged horse specimen reunited with its fourth, white leg. Photograph by Laura Smyk. © Canadian Museum of Nature

Vignette 3. Diverse objects present diverse labelling challenges.

The wide range of object types, materials, sizes, and uses found in collections leads to a great variety of identification techniques including direct numbering, tagging, labelled containers, etc.

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Figure 9a. Paper label adhered under tail feather of taxidermied bird. Photo by Robert Waller. © Canadian Museum of Nature

Figure 9b. Insect and label held together on a pin. Photo by Francois Genier.
© Canadian Museum of Nature

Figure 9c. Microscope slides with ink on glass, ink on paper, ink on paint, embossed plastic, and inscribed numbers. Photo by Judith Price.
© Canadian Museum of Nature

Figure 9d. Skeletal specimen with number in ink written directly on bone
© Canadian Museum of Nature

Figure 9e. Archaeological textile in a dedicated labelled box.

Figure 9f. For diverse collections labeling kits appropriate for labeling a range of object types are available (photograph courtesy of Northern States Conservation Center).

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Figure 9g. Paper specimen tag attached by string to a bird study skin. Photo by Robert Waller. © Canadian Museum of Nature

Figure 9h. Label sewn on to textile. Canadian Museum of Civilization, IMG2012-0264-0001-Dm.

Figure 9i. Tag attached to basket. Canadian Museum of Civilization, IMG2012-0264-0002-Dm

Figure 9j. Direct labeling of basket pictured. Canadian Museum of Civilization, IMG2012-0264-0003-Dm.

Figure 9k. Tags attached to sculpture support. Canadian Museum of Civilization, IMG2012-0264-0004-Dm.

Figure 9l. Tag on rolled textile. Canadian Museum of Civilization, IMG2012-0264-0005-Dm.

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

Figure 9m. Number written directly on ceramic object. Canadian Museum of Civilization, IMG2012-0264-0006-Dm.

Figure 9n. Identification label on shelf holding a canoe. Canadian Museum of Civilization, IMG2012-0264-0007-Dm.

Figure 9o. Direct labeling of canoe in figure 9l. Canadian Museum of Civilization, IMG2012-0264-0008-Dm.

Figure 9p. Identification label and numbers written on ivory. Canadian Museum of Civilization, IMG2012-0264-0009-Dm.

Figure 9q. Internal labels in fluid preserved specimen jars.

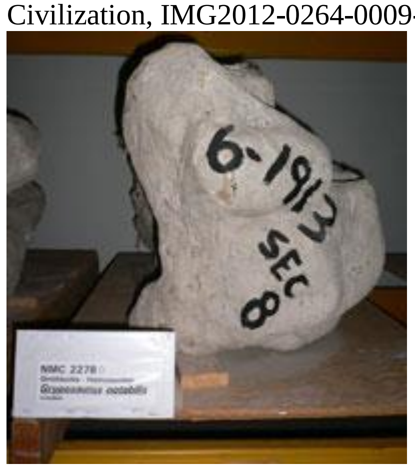

Figure 9r. Shelf label and identifying numbers painted on plaster jacket holding fossils. Photo by Robert Waller. © Canadian Museum of Nature

Vignette 4. Note on Historical Labels

Meticulous primary collectors will label objects soon after acquisition, and although these labels primarily contain information, they may also have aesthetic and historical value. The information on the labels is generally transcribed to the institution's own system, but the individual details of handwriting, etc., remain of historical and sometimes aesthetic interest. Over time the label paper can become very fragile, inks may fade, and adhesives can also weaken. Such labels should be treated with great care. Deteriorating labels may be encased in Mylar and remain directly attached to the object. If labels become detached, a decision is required whether or not they should be re-adhered. This requires analyzing the

https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html

risks and benefits of re-adherence relative to separate storage. If labels are not to be re-adhered to the object, they should be enclosed in a clearly identified poly(ethylene terephthalate) or Melinex envelope, which is closely referenced to the object. This discussion has focused on attached historical labels. Similar issues arise when considering detached object labels, sometimes called tray labels.

Figure 10. A historical collector's label associated with a quartz mineral specimen.
© Canadian Museum of Nature

Figure 11. Original tags, encased in Mylar, remain attached to an Octodon degu collected during the U.S. Exploring Expedition of 1838- 1842; ca. 1985.
© Catharine Hawks.

Figure 12. Historical labels preserved in separate file.
© Catharine Hawks.

References

1. Canadian Conservation Institute. **Applying Registration Numbers to Paintings**. CCI Notes 1/5. Ottawa: Canadian Conservation Institute, 1994a.
2. Canadian Conservation Institute. **Applying Accession Numbers to Textiles.** CCI Notes 13/8. Ottawa: Canadian Conservation Institute, 1994b.
3. Ogden, Sherelyn, ed. **Caring for American Indian Objects.** St. Paul, MN: Minnesota Historical Society Press, 2004, pp. 214–220.

Key Readings

1. Buck, Rebecca A., and Jean Allamn Gilmore. **Museum Registration Methods.** Washington DC: American Association of Museums, 1998.
2. Malaro, Marie C. **A Legal Primer on Managing Museum Collections**. Washington DC: Smithsonian Institution Press, 1998.
3. Museum Documentation Association. **Labelling and Marking Museum Objects**. SPECTRUM Procedure: Acquisition - Step 13.
4. Simmons, J.E. **Things Great and Small: Collections Management Policies.** Washington DC: American Association of Museums, 2006.

Glossary

Acquisition

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The appropriately documented transfer of title to the museum of an object or objects acquired by purchase, gift, bequest, field search, exchange or any other method, which transfers title to the museum.

Labelling

The process of preparing and affixing labels to folders, other file units, and containers; process of preparing labels to accompany objects or specimens.

Permit

A document which grants a person the right to do something not forbidden by law but not allowable without such authority.

Registration

The process of developing and maintaining an immediate, brief, and permanent means of identifying an object for which the institution has permanently or temporarily assumed responsibility.(definitions taken from Cato, P. S., Golden, J. and McLaren, S. B. (eds.). 2003. MuseumWise: Workplace Words Defined. Society for the Preservation of Natural History Collections, 388 pp.)

Thanks to the Centro Nacional de Conservación y Restauración in Chile, the Canadian Conservation Institute's web resource Agents of deterioration, translated into Spanish by ICCROM, is now available free of charge. Intended for curators and conservators, the resource identifies 10 primary threats specific to heritage environments.

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