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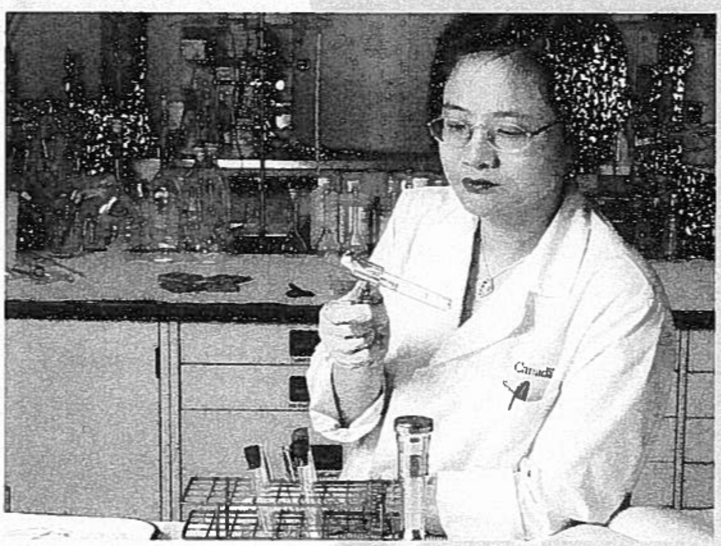
Coatings for Display and Storage in Museums



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Coatings for Display and Storage in Museums

by Jean Tétreault

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Abstract

Coatings are used in museums, archives, and galleries for new construction, storage facilities, or exhibitions; but coatings have the potential to cause damage (such as corrosion and discoloration) to objects either by direct contact or the emission of volatile compounds. Most problems caused by contact can be solved by using interleaves, and problems related to volatile emission can be controlled by selecting appropriate coatings and allowing adequate drying periods. Coatings formed by oxidative polymerization (such as oil-based or alkyd coatings) emit harmful volatile compounds and should be avoided in conservation contexts. Other types of coatings are usually acceptable provided sufficient drying time is allowed: 4 days is usually enough in a ventilated room, but up to 4 weeks may be required in airtight enclosures such as well-sealed display cases and cabinets.

The general recommendations in this document are based on the nature and use of the coatings rather than their trade names, as formulations may change. Information on the nature of coatings can be obtained from technical data or material safety data sheets, or tests can be run to determine the properties of a coating. The use of appropriate procedures and mitigation strategies will minimize any risk of damage.

CCI can help you to define the necessary specifications for your coating projects, and can perform a variety of physical and chemical tests to ensure that those specifications are met.

Author

Jean Tétreault earned a M.Sc. in Analytical Chemistry at the University of Montreal, and has worked as a conservation scientist in the Preventive Conservation Services Division at CCI since 1989. He was President of the Canadian Association for the Conservation of Cultural Property from 1995 to 1997.

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1. Introduction

Coatings*[1] such as paints* and varnishes* are often used in museums* for aesthetic reasons as well as for the protection of buildings and display cases, cabinets, or transportation cases. The requirements for coatings used for preservation purposes differ from those used for domestic or industrial purposes. Coating the interior of a display case is one example of a challenging situation that museums face regularly: coatings usually emit a large range of volatile compounds* and there is often a very short drying period* available before the installation of objects*, so emissions from a coating can create a harmful environment for objects in a display case.

The goal of this document is to alert architects, designers, contractors, fabricators, project managers, and museum staff to the damage that coatings might cause to objects, and to provide guidelines for the selection of coatings that will help minimize this risk. A list of coatings is provided for many different situations and, when possible, alternative materials and procedures are given. Recommendations are based on the various classes of coatings and resins*; trade names are not specified because there is a large variety of coatings on the market and their formulations may change in the future. Tests that will verify coating specifications or monitor the emission of volatile compounds are described, and information on substrate* surface preparation is also provided.

2. The Problem

Coatings can damage objects in two ways: by direct contact with the object or by emitting volatile compounds in the environment of the object.

2.1 Contact

Problems of direct contact range from a drop of coating falling on an object (worst case), to touching a coated surface that is still tacky, to the deposition of coating dust resulting from friction. Objects should be removed from a location where coating work is being done; if this is not possible they must be well protected.

Problems may also arise when objects are placed on a newly coated surface, e.g. when an object is hung on a newly coated wall or installed on a newly coated display panel. Contact with the coating components can dissolve or discolour the surface of the object, and when the object is removed some of its parts may remain adhered to the coated surface or vice versa. In most cases, risk should be minimal if a newly coated surface is allowed to dry for 4 weeks before contacting an object. However, there are always exceptions: coatings from unbalanced formulations (especially with black-pigmented coatings) or two-part coatings inadequately mixed can remain tacky for years. For optimal security, acid-free paper, some type of textile, a sheet of Mylar (Melinex), a polyethylene sheet, or foam should be used as an interleaf to eliminate any possibility of component transfer as a result of direct contact. Long-term contact between an object and a potentially reactive uncoated material (such as wood, metal, or concrete) should also be avoided.

The friction of opening coated metal or wooden drawers or doors may generate dust from the dry film* or the substrate. Fine dust can be difficult to remove, especially from porous or cracked objects, and may eventually stain the object. A good abrasion-resistant* film is required for drawers, as well as good handling and adequate loading.

2.2 Presence of Volatile Compounds

Some objects are vulnerable to the volatile compounds released by liquid coatings, e.g. metal objects can corrode and photographic materials can be discoloured in the presence of carboxylic acids, formaldehyde, and peroxides. Appendix 1 provides a list of objects known to be vulnerable to harmful volatile compounds or pollutants* released by coatings and substrates, and Appendix 2 gives the origin of these compounds along with the maximum concentration that is safe for conservation purposes. There is no liquid coating that is ideal for all museum situations. However, the risk of damage to an object can be assessed by looking at a number of parameters, including the type of coating and volatile compounds, the nature of the object, the type of enclosure*, and the drying period.

To avoid exposure to volatile compounds, objects should ideally be removed from a location where coating work is being done and not returned until after an adequate drying period. If this is not possible, they must be well protected with a covering that is as airtight as possible, especially for acid-sensitive objects.

Volatile Compounds and Coatings

Volatile compounds are released during the evaporation of the solvent and/or by chemical reactions during the formation of the film. Most coatings release a large variety of volatile compounds. Figure 1 illustrates the typical emission decay over time for a single volatile and for the total volatile compounds released by a film. The general tendency of the emission rate is to decrease rapidly for the first few days, and then level off or at least slow down after 4 weeks. Even after stabilizing, some volatile emissions (e.g. those that result from slow ongoing coating degradation processes) can remain high enough to be potentially harmful to vulnerable objects.

The nature of coating components (resin, solvent, and additives) and the type of film-forming mechanism

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[1] All terms marked with an asterisk are defined in the Glossary.

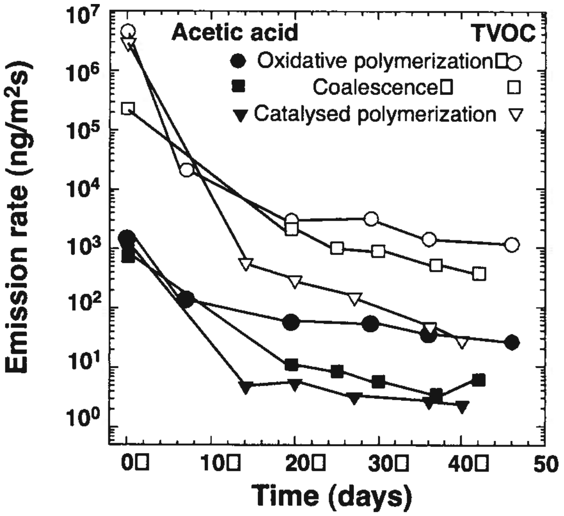

Figure 1. Volatile emission decay over time [1].

(described below) provide information on the presence and levels of volatile compounds. For example, if calcium carbonate (an extender pigment) is present it will absorb and neutralize acidic volatile compounds in the coating and may help to maintain a low emission of these acids. The nature of the coating components also provides information on the impermeability of the film, which is important if a substrate releases volatile compounds. For example, a good vapour barrier is required if the substrate is a wood product such as particleboard, with urea formaldehyde-based adhesive. The unstable adhesive releases high levels of formaldehyde which is known to be harmful not only to many metal objects but also to human beings. The permeability of a coating depends not only on the nature of its components but also on the thickness of the film. Methods to reduce the generation of volatile compounds from both films and substrates are discussed later in this document.

Objects

The nature of an object is an important factor to consider when assessing the risk of exposure to a coating, e.g. new glass and ceramic objects are usually not sensitive to volatile emissions from coatings whereas most metal objects and photographic materials are acid-sensitive* and, to some extent, oxidant-sensitive* (see Appendix 1 for an extended list of vulnerable objects). Damage to objects can be difficult to evaluate because, although detectable at a microscopic level, it can be invisible at a macroscopic level. Repeated exposures to inappropriate films may cause an accumulation of these small alterations on objects.

Most objects tend to degrade slowly over time and can release the same type of volatile compounds as do new coatings. For example, ethnographic objects composed of skin, leather, wood, or paper and some synthetic materials such as cellulose acetate film can all release carboxylic acid volatile compounds. Potential damage to objects should not be a prime concern when the objects are more emissive than the coating, but the opposite situation could cause problems. In some cases, volatile compounds from a coating can damage an object by autocatalytic reactions*, e.g. acetic acid released by many coatings can speed up the degradation of papers and cellulose acetate based films.

Enclosures

The level of volatile compounds is affected by the degree of ventilation in an enclosure or in the immediate environment of the coated structure. In this document, enclosures are categorized as one of three types depending on their typical air exchange rates*: airtight enclosures (≈1 air exchange per day); leaky enclosures (≈10 air exchanges per day); and open enclosures (≈100 air exchanges per day).

Figure 2 shows the evolution of the concentration of volatile compounds in these three different types of enclosures. The higher the air exchange rate in the enclosure, the lower the initial steady-state concentration* of volatile compounds, and the easier the dissipation of volatile compounds over the time.

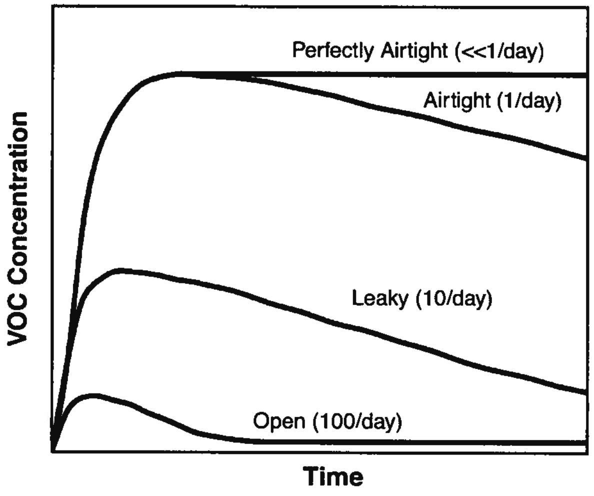

Figure 2. Evolution of the concentration of volatile compounds in different types of enclosures.

Airtight (closed) enclosures such as display cases, cabinets, and transportation cases offer good protection against external pollutants, dust, and insects, and can also make it easier to control temperature and relative humidity (RH). To obtain an airtight enclosure, gaskets are frequently used and the seams of the structural elements are sealed with adhesive. Volatile compounds emitted from coated hardware items or objects inside the enclosure cannot escape easily, and increase to a steady-state concentration close to the equilibrium concentration* that can be maintained for several months. Vulnerable objects within the enclosure are likely to be damaged by the volatile compounds released by the coating itself or by the emissive substrate through the film. No liquid coating is completely impermeable and none can provide an environment within the airtight enclosure that is completely free of harmful volatile compounds.

The situation is less critical inside leaky enclosures, which have natural or designed gaps and holes ranging from a few millimetres up to 2 cm. Steady-state concentrations of volatile compounds are lower in leaky enclosures than in airtight enclosures, and are particularly influenced by the ratio of the area of coated surface in the enclosure to its volume (m^2/m^3). The lower this ratio, the lower the initial steady-state concentration, the easier the dissipation of volatile compounds, and therefore the shorter the drying period required. A display case with one coated side is an example of an enclosure with a low ratio of coated surface area to volume, and a map storage cabinet with many coated drawers is an example of one with a high ratio.

In open enclosures, volatile compounds reach low steady-state concentrations and are easily dissipated. Examples of open enclosures include open or ventilated cabinets, a shelving unit in a room, or the room itself.

Drying Period
The drying period can vary depending on the required result: a dry-to-touch* feel, a non-tacky surface (dry-hard*), or the readiness for recoating. In this document, the drying period will be the time required for the rate of evolution of volatile compounds to decrease to a level such that steady-state concentrations in the enclosure or room will be acceptably low.

After type of enclosure, drying period is the next key parameter to be chosen. The longer the drying period, the lower the concentration of volatile compounds for a specific air exchange rate (Figure 2). A drying period of 4 weeks is generally sufficient to allow the emission of volatile compounds to level off; additional time beyond this point has very little effect.

It is generally best to avoid using coatings that are suspected to release harmful volatile compounds. This rule is especially important when objects are particularly sensitive and will be in an airtight enclosure. Lead, probably the most carboxylic acid sensitive material, is a good example; if lead artifacts are to be in an airtight enclosure, only some plastic or powder coatings are acceptable for that enclosure. Fortunately, many situations are less critical and the rule does not always have to be followed so closely. Small precautions can often ensure a low concentration of volatile compounds in an enclosure, e.g. choosing proper coatings and allowing a 4-week drying period for a coated leaky enclosure or an open enclosure such as a gallery room. In such cases, the presence of other agents of deterioration (e.g. light, RH, and insects) is probably a more serious problem than emission of volatile compounds.

The recommendations in this document are based on the interaction between volatile compounds and objects, and the typical steady-state concentration of volatile compounds that a particular coated enclosure will reach in a specific situation. The recommendations do not replace the need for testing coating components and film characteristics for important coating projects, but may help to increase awareness of potential problems and provide guidelines for the most frequent situations found in museum contexts.

3. Classification of Coatings

In this document, coatings are classified according to their film-forming mechanisms. A film is the result of the conversion of the coating, usually a liquid, to a solid film. Seven common film-forming mechanisms are described, and general recommendations are provided for each.

3.1 Solvent Evaporation*

A dry film (referred to as lacquer*) is formed by simple evaporation of the solvent of a liquid coating. Resins in this category include shellac, cellulose nitrate, ethyl cellulose, ethyl hydroxy ethyl cellulose, and acrylic esters such as Acryloid. Most films formed by solvent evaporation have a low solid content* and require more layers than other coatings to provide an adequate vapour barrier.

The most common film formed by solvent evaporation is shellac, which is made by dissolving shellac flakes in alcohol. It is available in both orange and white (bleached) products, but the orange form is a better sealer for knots and does not contain bleaching agent residues. The main disadvantage of shellac is its high vulnerability to water stains; surfaces coated with shellac are moisture-sensitive and should not be touched by visitors.

Another common film formed by evaporation is cellulose nitrate, but it may contain drying oil-based compounds* and ethyl acetate, which can be corrosive. Also, in airtight enclosures there is a risk of long-term emission of nitrogen oxide(s).

Some acrylics are formed by solvent evaporation but they may contain an acetate-based solvent known for its corrosion capacity.

3.2 Coalescence*

A film is formed by coalescence of the polymer* particles (driven by surface tension and capillary force) after an emulsion* (latex*) coating is applied and most of the water has evaporated. These coatings are easy to work with and environmentally friendly, but tend to be porous. Their permeability to volatile compounds can range from poor to good. Commonly used resins include acrylic, vinyl acetate, vinyl acetate-acrylic, acrylic-styrene, butadiene-styrene, urethane, and acrylic-urethane (these two urethanes are fully reacted).

The main museum pollutants found in these coating formulations are water, ammonia, formaldehyde, and carboxylic acids. The first three are free in the emulsion and evaporate rapidly. High levels of water vapour in airtight enclosures recently coated with films formed by coalescence can cause mould growth and corrosion problems. Carboxylic acids (such as acetic acid) are also found free in the emulsion but they evaporate slowly; these acids can also result from a degradation process of the film (e.g. hydrolysis of the vinyl acetate component). Emulsion coatings contain varying percentages of adsorption/reaction materials* (such as calcium carbonate, an alkaline extender pigment), making the rate of emission of acidic volatile compounds very unpredictable. Coatings with as much alkaline extender pigment as the aesthetic (gloss* and powdery finish) requirement will allow are recommended.

3.3 Oxidative Polymerization*

A film is formed by the autoxidation of non-conjugated unsaturated fatty acid components in alkyds (or drying oils), which form conjugated hydroperoxides, which break down to radicals and then promote polymerization* by cross-linking* reactions. The oxidation processes lead to aldehydes and alkyl radicals, which are oxidized to carboxylic acid forms. This category includes drying oils and alkyds* (oleoresinous coatings, air-dried coatings, enamel*), oil-modified urethanes (urethane oil, urethane alkyd, liquid plastic), and epoxy esters (one-part epoxy).

Many films are formed by oxidative polymerization at room temperature but they are not generally appropriate for museum purposes because the process is slow and generates a variety of pollutants. Formic acid is the major oxidative constituent although peroxides, aldehydes, and carboxylic acids up to 10 carbons have also been identified during the first few days. Oxidative activities in the film can continue for up to a year. However, when oxidative polymerization is done in high temperature (a situation usually found with baked enamel coatings on metal structures), the problem of volatile compounds is reduced. The baking process speeds up the polymerization and most volatile compounds are released during the process. Underbaking must be avoided as it can result in some coated metal structures still releasing small amounts of formaldehyde and some carboxylic acids.

3.4 Moisture-cured Polymerization*

A film is formed by polymerization when water vapour from the atmosphere interacts with the isocyanate group, usually tolylene diisocyanate (TDI), to form urea linkages. The optimum RH range for this process is 35–85%; dry environments such as those found during cold winter months in heated buildings without moisture control may inhibit the cross-linking process. The only example of this type of film is moisture-cured urethane, which normally has good abrasion resistance*, low levels of acidic volatile emission, and good barrier properties. Its main disadvantages are the strong odour of the isocyanate compound (which irritates eyes) and the danger of yellowing objects during evaporation if ventilation is inadequate. Fortunately, in response to health regulations, many coating companies are reducing the amount of isocyanate compounds.

3.5 Catalysed Polymerization*

A film is formed by cross-linking two different components in the presence of catalysts* (accelerators or cross-linking agents), some of which may enter into the reaction and become part of the cross-linked system; this does not require an external agent. The most common example in this category is epoxy film, which results from the cross-linking of two different epoxies or an epoxy polymer and a monomer such as amine compound. Epoxies that contain organic solvents might wrinkle or lift previous films, so it is recommended that a film adhesion test (Test 16) be done to check the compatibility of coatings. If the epoxy causes any reaction with the previous film, the previous film must be removed or another type of coating considered.

Urethane films in this category are formed by a reaction between the prepolymer (which contains an isocyanate group) and a catalyst or hydroxyl compound (polyol). A small amount of TDI is often present in this mechanism, and formaldehyde is found occasionally. The polyol can be a polyether, a polyester (such as acrylate compounds), or an alkyd (mainly castor oil); the alkyd should be avoided. One-package heat-cured urethane (blocked isocyanate system) is also formed by catalysed polymerization; in this instance the reactive components are mixed together in the same package but the presence of a blocking agent such as an alcohol or phenolic compound inhibits the reaction. The cross-linking occurs when the blocking agent evaporates, usually by heating.

The physical properties of epoxy and urethane films formed by catalysed polymerization vary depending on the ratio of the components. Epoxies are usually formulated to have good resistance to chemical attack (solvents, acids, etc.) with fairly good resistance to abrasion, and urethanes are usually formulated to have good resistance to abrasion with fairly good resistance to chemical attack. Both are very good vapour barriers.

Incorrect combinations of the components of these coating systems or inadequate mixing are frequent concerns in conservation: unreacted compounds can alter objects, e.g. acid anhydrides and some amine compounds can corrode metals (Appendix 1), and inadequately mixed coatings can leave surfaces tacky. These coatings are also difficult to find in local paint stores, expensive, and have a limited pot life after the components are mixed.

3.6 Change-of-phase*

Films formed by the change-of-phase principle (also called heat fluxing) are most often applied to metal structures by dry powder spraying (electrostatic spraying) followed by heating to form a film. Epoxy, polyester, urethane, acrylic, or combined components are common solid powdered resins, referred to as powder coatings. The main advantage of powder coatings is the absence of solvent, which eliminates the problem of emission of volatile compounds. Epoxy resins have the best chemical resistance and acrylic resins have the lowest. Powder coatings are currently one of the most environmentally friendly choices, and the price is becoming competitive with baked alkyd coatings.

3.7 Mixed Mechanisms

Films may be formed by more than one mechanism, e.g. powder thermosetting* films are formed by catalysed polymerization in addition to change-of-phase, and two-part epoxy emulsions are formed by coalescence and catalysed polymerization. The characteristics of these films tend to be intermediate between those of films formed by either mechanism alone, e.g. the vapour barrier provided by two-part epoxy emulsions is inferior to that of epoxy films formed by catalysed polymerization, but superior to most films formed by coalescence.

Other types of film-forming mechanisms such as heat conversion, cross-linking irradiation, and electrodeposition are not covered in this document.

4. Coatings for Different Substrates

Three groups of substrates are discussed in this chapter: wood and wood products, metal, and masonry and cementitious substrates. Coatings for different indoor purposes are suggested for each group, and some information on surface preparation is provided. Table 1 provides a summary of the recommended coatings and drying periods for different substrates and types of enclosures. The recommended drying periods usually vary from 4 days to 4 weeks, depending on the tightness of the enclosure. The 4-week drying period is based on the time required for the concentration of volatile compounds to stabilize for most coatings (see Section 2.2 "Volatile Compounds and Coatings") and the 4-day period is based on the time required for a film formed by chemical reactions to cure completely; 4 days is also the time when volatile compounds from a film formed by coalescence no longer give off a detectable odour in a ventilated room.

These recommended drying periods are probably longer than museums can afford to provide, but perhaps the information in this document can be used to negotiate a longer drying period at the planning stage. When the recommended drying period cannot be respected, some mitigation strategies (see Table 5 on page 15 for examples) should be considered.

4.1 Wood and Wood Products

Wood, especially knots, can damage objects (e.g. staining porous objects such as textile and paper) so direct contact should be avoided by using interleaves. Acidic emission from wood and wood products is another important concern. Acetic acid, one of the major volatile compounds emitted by wood, is formed by hydrolysis of the hemicellulose acetyl groups. Its content in wood depends mainly on the nature of the wood species and the location of samples. The acidity of the volatile compounds released by wood can be determined by various techniques (see Tests 4, 6, and 7); because there is a rough correlation between the pH of a wood species immersed in water and the acidity of the volatile compounds in an airtight enclosure, the wood acidity test (Test 5) can also be used for this purpose. An alternative to testing is to choose the least acidic woods. A list of wood species with their respective pH values is given in Table 2. Any wood with a pH less than 5 should not be used in airtight enclosures.

Economy, availability, uniformity, and size are some of the reasons for the widespread use of man-made boards or wood products such as plywood, waferboard (flakeboard, oriented strand board), particleboard (chipboard), and fibreboard* (MDF). These materials are generally composed of particles of several different wood species held together with an adhesive. The acidity of a composite wood product tends to be an average of the acidities of all the wood species present; but the exact composition of these wood products is sometimes uncertain, making it difficult to estimate their acidity without actual measurements. Plywood offers some choices for veneer as well as for inner plies, but choice of wood species is limited in waferboard, particleboard, and fibreboard. The choice of the proper wood species can be difficult but choosing the right type of adhesive is even more critical.

A wood product may contain a lot of very emissive adhesive. The most common adhesives are based on formaldehyde-containing resins, and formaldehyde is known to cause deterioration of metal and calcium-based objects when carboxylic acids are present; the chromotropic acid test (Test 2) can be used to determine the emission of formaldehyde. Choosing a board glued with phenol formaldehyde, which is weather-resistant and usually designated for exterior use, will minimize the emission of formaldehyde. Phenol formaldehyde is preferable to urea formaldehyde, which releases large amounts of formaldehyde in the presence of moisture. Fortunately, as a result of health considerations, the use of phenol formaldehyde in wood products is increasing. Choosing wood fibreboard with a polyurea-based adhesive sometimes referred to as zero-formaldehyde (Medite II) will also solve the problem of emission from the adhesive.

Various alternatives exist to avoid the problem of emission from wood and adhesives, the best being the use of non or low emissive materials such as glass, metal (e.g. stainless steel, aluminum honeycomb panel), or some hard plastics (e.g. ABS, acrylic, polycarbonate, fibreglass). Some designers propose display cases made of glass and metal, with wood restricted to the outside part of the case. When the use of wood is inevitable inside an enclosure, a plywood panel covered with a vapour barrier laminated shield made

Table 1. Classification of coatings and summary of coating recommendations.

Classification of Coatings by Film-forming Mechanism

Class	Examples
Solvent evaporation (SE):	shellac, cellulose nitrate
Coalescence (C):	emulsion, latex, water-based
Oxidative polymerization (OP):	oil, alkyd, epoxy ester, oil-modified urethane
Moisture-cured polymerization (MC):	moisture-cured urethane
Catalysed polymerization (CP):	two-part epoxy, two-part urethane
Change-of-phase (CoP):	powder coatings

Summary of the Coating Recommendations

Legend and notes: DP, drying period; w, week; d, day; AE, air exchange rate; ◊, should not have components formed by oxidative polymerization; □, high amount of calcium carbonate is preferable; ○, varnishes need more layers; ✚, drying period will vary depending on the ratio of the coated surface to the volume of the enclosure.

	Wood products	DP	Metal	DP	Cementitious subst.	DP
Airtight enclosures (AE ≈ 1/day)	epoxy CP, CP+C urethane CP◊ all films C◊,□ shellac SE○	4w 4w 4w 4w	all films CoP epoxy CP, CP+C urethane CP◊ acrylic C	1d 4w 4w 4w	epoxy CP, CP + C urethane CP◊ all films C◊	4w 4w 4w
Leaky enclosures✚ (AE ≈ 10/day)	epoxy CP, CP+C urethane CP◊, MC shellac SE○ all films C◊,○	2–4w 2–4w 2–4w 2–4w	all films CoP baked alkyd OP epoxy CP, CP+C urethane CP◊ acrylic C	1d 2–4w 2–4w 2–4w 2–4w	epoxy CP, CP+C urethane CP◊,MC all films C◊	2–4w 2–4w 2–4w
Open enclosures (AE≈100/day)	epoxy CP, CP+C urethane CP, MC all films SE, C◊	4d 4d 4d	all films CoP baked alkyd OP epoxy CP, CP+C urethane CP acrylic C	1d 4d 4d 4d 4d	epoxy CP, CP+C urethane CP, MC all films C◊	4d 4d 4d
Floors (AE ≈ 100/day)	urethane CP, MC, C epoxy CP, CP+C acrylic-urethane C	4d 4d 4d	all films CoP baked alkyd OP urethane CP epoxy CP, CP+C	1d 4d 4d 4d	urethane CP, MC, C epoxy CP, CP+C acrylic-urethane C	4d 4d 4d
Contact between objects and film	interleaves all films◊	4d 4w	interleaves all films CoP baked alkyd OP unbaked films◊	4d 1d 2w 4w	interleaves all films◊	4d 4w

of phenol formaldehyde such as a medium- or high-density overlaid plywood (MDO/HDO) (or film-faced plywood) is an option. A laminated plywood, especially a high-density one, provides a fairly good barrier to the volatile compounds coming from both the wood and the adhesive. Medium- and some high-density overlaid plywoods are designed so they can be coated, but most high-density overlaid plywoods do not have adequate film adherence.

Particleboards may be laminated with high-pressure decorative laminates with phenol and/or melamine formaldehyde binders such as those used for kitchen counters or low-cost book shelves. The laminated board already has a finished appearance and the laminate emits fewer volatile compounds than a freshly applied coating, but the substrate (particleboard) can contain high levels of formaldehyde from its urea formaldehyde resin, and also some carboxylic acids generated by hydrolysis reactions enhanced by the high porosity of the board. The unsealed edges of laminated wood products can be so emissive that they override the vapour barrier effect of the laminated surface panels and generate a high level of volatile compounds inside an enclosure. Therefore, the edges must be coated or sealed with a vapour barrier film, and the seams should also be sealed, e.g. with a hot glue gun.

Hardboard (wood fibre) can be impregnated to improve its compressive strength and hardness; densified fibreboards are called tempered* hardboards* or tempered Masonite (Isorel). Densifying can be done with phenol formaldehyde, molten natural resins, or sulphur compounds, but woods densified with oxidative resins and sulphur compounds should not come in direct contact with objects or be used in airtight enclosures. Fibreboards densified with drying-oils (i.e. linseed oil or tung oil) release carboxylic acids and should also be avoided.

Surface Preparation

Proper surface preparation will maximize the vapour barrier performance of a film on a wood substrate. Uncoated solid woods and wood products should be stored in a warm, dry room to prevent absorption of moisture, shrinkage, and roughening; their moisture content should be less than 15% (Test 15). Surfaces should be sanded smooth, always along the grain, but the surface must be dust free before coating. The traditional paint system for wooden substrates includes a primer* sealer, an undercoat*, and a topcoat*. Wood species with an open grain* (such as oak, chestnut, ash, mahogany, and cherry) may require a wood filler* before the primer, especially if a varnish is to be used.

Varnishes or glossy surfaces of previous films should be sanded lightly to a dull finish between coatings.

Airtight Enclosures

Airtight enclosures present special problems because the volatile compounds released by wood can accumulate to dangerously high levels. Special attention must be paid to the edges of wood panels which are almost ten times as emissive as the face panels. Most films can only reduce this emission, not block it completely. The thicker a dry film, the more it will reduce the emission of volatile compounds from the substrate. The barrier effect of a film can also be increased by adding extra layers. In general, a drying period of 4 weeks is required for coatings inside airtight enclosures, especially if they will contain acid-sensitive objects.

The following coatings are suggested for wood in airtight enclosures:

Paints: epoxy and urethane (without alkyd polyols and acids) formed by catalysed polymerization; those formed by coalescence (including two-part epoxy emulsions) are acceptable if they have a lot of calcium carbonate and very few free carboxylic acids.

Varnishes: orange shellac (additional layers) and epoxy or urethane (without alkyd polyols and acids) formed by catalysed polymerization.

Stains*: stains formed by coalescence can be used only as an undercoat because they have a low solid content and consequently are poor vapour barriers; a varnish should be used as the topcoat.

Stoppers*, Wood Fillers, and Primers: these should not contain resins formed by oxidative polymerization.

Even when using a recommended coating, the acidic volatile compounds in a coated enclosure should be measured before it is used and, if possible, after (see Tests 4, 6, and 7). If the level is unsatisfactory, mitigation strategies should be considered (see Table 5 on page 15), e.g. increasing the rate of air exchange in the display case, extending the drying period, using absorbent materials, or decreasing the RH in the enclosure.

Vapour barrier films such as plastic-coated aluminum foil block the emissions from wood [17] and can be used as an alternative to coatings. They have a shiny appearance and cannot be coated, although covering them with coloured matboard or fabric is an option. No emission can pass through these barrier sheets, which can be applied to a wooden panel with a hot spatula or iron.

For new wooden transportation cases that are designed to contain objects for only a short time, the application of coatings can sometimes be avoided. If a 4-week drying period is not available, it is preferable that the interior of the case remain uncoated. Instead, carefully wrap the objects with tissues and/or with plastic sheets; wrapping objects will protect them against pollutants and wooden dust for a short time. An uncoated transportation case should not be used for long-term storage, especially for acid-sensitive objects, but sealing the interior of the case with a vapour barrier film would make this an option.

Table 2. Acidity of different wood species.

Genus and species	English	French	pH*	Ref.
Dalbergia melanoxylon	African blackwood	blackwood d'Afrique	8.0	2
Populus cathayana	Korean poplar	peuplier cathayana	7.5–8.0	3
Gossypiospermum praecox	Maracaibo boxwood	zapatero	6.9	2
Ulmus procera	English elm	orme champêtre	6.8	4
Khaya ivorensis	African mahogany	acajou Grand Bassam	6.5	5
Acer saccharinum	silver maple	érable argenté	6.4	6
Populus balsamifera	balsam poplar	peuplier baumier	6.4	6
Abies grandis	grand fir	sapin grandissime (sapin de Vancouver)	6.2	6
Ulmus americana	American white elm	orme blanc d'Amérique	6.0–7.6	3, 6
Acer pennsylvanicum	striped maple	érable de Pennsylvanie	6.0	6
Abies lasiocarpa	Alpine fir	sapin subalpin	6.0	6
Abies amabilis	amabilis fir	sapin gracieux/amabilis	5.9	6
Alnus rubra	red alder	aune rouge/de l'Orégon	5.9	6
Fraxinus excelsior	European ash	frêne commun	5.8	2
Erythrophleum micranthum	missanda, tali	tali	5.8	5
Populus grandidentata	largetooth aspen	peuplier à grandes dents	5.8	6
Dyera costulata	jelutong-bukit	jelutong-bukit	5.7–6.1	7
Tetramerista spp.	punah	punah	5.7–6.0	7
Picea mariana	black spruce	épinette noire (sapinette noire)	5.7	6
Tsuga canadensis	eastern hemlock	tsuga du Canada/ de l'Est	5.5–6.2	3, 6, 8
Fagus grandifolia	American beech	hêtre à grandes feuilles (hêtre américain)	5.5–6.2	3, 6
Picea glauca	eastern Canadian spruce	épinette blanche (sapinette blanche)	5.5	6
Picea rubens	Canadian red spruce	épinette rouge	5.5	6
Fraxinus nigra	American black ash	frêne noir	5.5	6
Chlorophora excelsa	iroko, kambala	iroko, kambala	5.4–7.3	2, 5, 9
Ochroma lagopus	balsa, corkwood	balsa	5.4–7.2	2, 4, 10, 11
Hevea brasiliensis	hevea, rubbertree	hévéa	5.4–6.0	7
Fraxinus americana	American hite ash	frêne blanc/d'Amérique	5.4–6.0	3, 6
Pinus banksiana	Jack pine	pin gris	5.4	6
Abies balsamea	balsam fir	sapin baumier	5.4	6
Populus tremuloides	quaking aspen	peuplier faux-tremble	5.4	6
Betula papyrifera	white birch	bouleau à papier	5.3–5.5	3, 6
Gonystylus bancanus	ramin	ramin	5.3–5.4	9
Robinia pseudoacacia	black locust, robinia	robinier faux-acacia	5.3	2, 12
Araucaria angustifolia	Parana pine	pin du Parana	5.2–8.8	9
Terminalia superba	afara, limba	limba	5.2–8.2	2
Pinus resinosa	red pine	pin rouge	5.2–6.0	3, 6
Liriodendron tulipifera	yellow poplar	tulipier d'Amérique	5.2–5.4	2, 8
Carpinus betulus	European hornbeam	charme	5.2	2
Larix laricina	tamarack larch	mélèze laricin/d'Amérique	5.2	6
Liquidambar styraciflua	sweet gum	copalme d'Amérique (gommier)	5.2	8
Dumoria heckelii	cherry mahogany, makoré	makoré	5.1–6.7	2, 5
Acer saccharum	sugar maple	érable à sucre	5.1–5.8	3, 6

Genus and species	English	French	pH*	Ref.
Betula populifolia	grey birch	bouleau gris (à feuilles de peuplier)	5.1	6
Ocotea rodiaei	Demerara greenheart	greenhart	5.0	4
Prunus serotina	black cherry	cerisier tardif	5.0	6
Acer rubrum	red maple	érable rouge	4.9–6.0	3, 6
Afzelia pachyloba	afzelia	doussié	4.9	2
Tsuga heterophylla	western hemlock	pruche occidentale	4.8–5.8	6, 10
Thuja occidentalis	eastern white cedar	thuya occidental	4.8	6
Shorea spp.	meranti	meranti	4.7	2
Lophira procera	ekki, red ironwood	azobé, bonkolé	4.7	2
Tilia americana	American limetree	tilleul d'Amérique	4.6–6.4	2, 6, 13
Betula alleghaniensis	yellow birch	bouleau jaune canadien	4.6–5.7	6, 8
Betula verrucosa	English birch	bouleau verruqueux	4.6–4.8	2, 11
Afzelia bipindensis	afzelia	doussié	4.6	5
Quercus suber	cork oak	chêne liège, surier	4.6	14
Khaya spp.	African mahogany	acajou	4.5–6.7	2, 4, 8, 10
Tectona grandis	teak	teck	4.5–5.5	2, 5, 6, 9, 10, 11
Triplochiton scleroxylon	obeche, wawa	obeche, ayous	4.4–6.8	4, 9, 10
Juglans regia	European walnut	noyer commun	4.4–5.2	2, 9
Pinus sylvestris	Scots pine	pin sylvestre	4.3–5.1	2, 10, 11
Entandrophragma cylindricum	sapele	sapelli, lifaki	4.3–5.0	2, 10
Afrormosia elata	kokrodua, asamela	kokrodua, asamela	4.3–4.8	2, 10
Mansonia altissima	mansonia, bété	bété	4.3	2
Schinopsis balansae	quebracho colorado	quebracho colorado	4.3	2
Aucoumea klaineana	gaboon, okoumé	okoumé	4.2–5.2	2, 9
Picea sitchensis	Sitka spruce	épinette de Sitka	4.0–5.5	6, 8, 10, 11
Picea abies	common spruce	épicéa commun	4.0–5.3	3, 4, 9, 10
Pinus strobus	white/yellow pine	pin blanc/Weymouth	4.0–5.3	3, 6, 13
Larix decidua	common larch	mélèze commun/d'Europe	4.0–5.7	2, 10, 12
Fagus sylvatica	European beech	hêtre commun/européen	3.9–7.2	2, 4, 9, 10, 11
Quercus petraea	sessile oak	chêne rouvre	3.9	2
Quercus velutina	black oak	chêne noir/des teinturiers	3.9	15
Quercus rubra	American red oak	chêne rouge (d'Amérique)	3.8–4.2	3, 13
Quercus alba	American white oak	chêne blanc (d'Amérique)	3.8–4.1	3, 13
Pinus pinaster	maritime pine	pin maritime	3.8	10
Pterocarpus soyauxii	African padauk	padauk d'Afrique	3.7–5.6	2, 5
Terminalia ivorensis	idigbo	framiré	3.5–4.1	10
Juniperus procera	juniper, African pencil cedar	genévrier d'Afrique	3.5	10
Castanea sativa	sweet chesnut	châtaigner	3.4–3.7	9, 10
Quercus robur	European oak	chêne pédonculé	3.3–3.9	10
Pseudotsuga menziesii	Douglas fir	Douglas vert	3.1–6.1	3, 6, 9, 10, 13, 15
Pseudotsuga taxifolia	blue Douglas fir	Douglas bleu	3.1–4.4	2, 4, 10, 11
Eucalyptus marginata	jarrah	jarrah	3.0–3.7	10
Thuja plicata	western red cedar	thuya géant	2.5–4.0	4, 6, 10, 11

* A single type of wood may display a very wide pH range, e.g. European beech varies between pH 7.2 and 3.9. This variability can be attributed principally to sampling [16] and the different experimental set-ups of various authors.

Leaky Enclosures
A leaky wooden enclosure requires less attention than an airtight enclosure because of the ongoing dissipation of volatile compounds. In addition to epoxy or urethane films formed by catalysed polymerization and shellac, most films formed by coalescence and moisture-cured urethane can safely be used. The drying period can be reduced down to 2 weeks if the enclosure has a low ratio of coated surfaces to volume (e.g. ≤ 1 m^2/m^3) but 4 weeks is still required if the coated surface will be in direct contact with an object. As with airtight enclosures, the level of acidic volatile compounds should be measured before the coated enclosure is used. If the level is unsatisfactory, it may dissipate gradually with leakage from the enclosure or mitigation strategies may be required.

Open Enclosures
With the exception of those formed by oxidative polymerization, most films can be used in open enclosures with only a 4-day drying period. This period must be extended for films formed by moisture-cured or catalysed polymerization if the coating company specifies a longer curing time.

When no special physical properties (e.g. abrasion or impact resistance) are required, films formed by coalescence are an economical choice. Wood shelves used to store heavy objects should be dealt with in the same manner as wooden floors.

Some open enclosures may contain areas with little air movement, such as a deep interior corner of a book shelf. These microenvironments are comparable to a leaky enclosure, so the concentration of volatile compounds should be monitored and the drying period adjusted accordingly. If there will be direct contact between a coated surface and an object, a period of 4 weeks is still required, and if the coating contains poly(vinyl acetate) or alkyd resin, an interleaf should be used to avoid transfer of acid compounds.

Floors
A wooden floor is a special type of open enclosure. The dissipation of volatile compounds is similar to open enclosures, and the same drying period (4 days) is suggested; but a floor must have good impact and abrasion resistance. For public traffic or heavy-duty use, urethane formed by moisture-cured or catalysed polymerization is usually a good choice. Stains formed by coalescence or oxidative polymerization (sometimes) can be used as an undercoat for varnish. In cases where chemical resistance is also required, epoxies formed by catalysed polymerization are recommended. Some acrylic-urethane or epoxy emulsions can satisfy the hardness and abrasion resistance requirements, but these characteristics must be confirmed by the coating manufacturer or tested by an independent materials science institute (Tests 10–13).

4.2 Metal

Metallic structures such as storage cabinets, shelving units, display cases, suspension racks, and structural beams are often used for museum purposes. Coatings are applied mainly for aesthetic purposes and to protect the metal against corrosion; stainless or galvanized steels may not require a coating. An uncoated metal surface may be acceptable if it will not come in contact with an object; however, when there is direct contact, an uncoated metal surface can stain objects so the use of an interleaf is necessary.

Coatings on metal cabinets and shelves are generally baked films. The two major types are formed by oxidative polymerization or change-of-phase (powder coatings); alkyd resin baked coatings are the most frequently used although powder coatings are increasing in popularity. For both types, the baking time and temperature can vary within a limited range, with longer times and higher temperatures giving harder films that have better resistance to chemicals. Hard films are necessary for metal cabinet drawers where the friction of opening and closing could generate dust. It is important to avoid underbaking, which has been reported to result in significant emissions of volatile compounds from alkyd coatings on cabinets. Contractors must be given specifications indicating the maximum concentrations of acid and formaldehyde vapours that are allowable inside enclosures when they are delivered (see Appendix 2 for appropriate levels of volatile compounds).

In circumstances such as a special installation for an exhibition or refreshing a metallic structure, the use of unbaked coatings is acceptable, e.g. some films (anti-rust) formed by coalescence and some urethane films formed by catalysed polymerization with an acrylate compound such as polyol can be used without baking.

Surface Preparation
Surface preparation and the application of baked films are usually done at a factory. The metal surface must be free of grease, dust, rust, or any loose contaminant; some metals such as aluminum need to be etched or pretreated before receiving a primer. The coating manufacturer should be consulted for detailed instructions on surface preparation.

Airtight Enclosures
The best coatings for airtight metal enclosures are baked films formed by change-of-phase (powder coatings); objects can be placed inside the enclosure the day after coating.

When an airtight metallic structure must be coated without a baking process, films formed by coalescence, and epoxies and urethanes formed by catalysed polymerization can be used. Primers containing poly(vinyl chloride)-acrylic resins (coalescence) are not acceptable because they can release a small amount hydrogen chloride, a strong acid.

Leaky Enclosures
Coating recommendations for leaky enclosures are the same as those for airtight enclosures: for baked alkyd films, films formed by coalescence, and films formed by catalysed polymerization, a drying period of 2–4 weeks is suggested depending on the ratio of coated surface to volume. The level of volatile compounds should be monitored for a few enclosures or for enclosures where a lot of emissions are suspected (Tests 4, 6, and 7).

Open Enclosures
As with the other types of enclosures, baked powder coatings can be used without delay in ventilated areas. For other films, a drying period of 4 days is usually sufficient although this time should be extended if microenvironments are suspected.

4.3 Masonry and Cementitious Substrates

Plaster*, gypsumboard*, concrete, and stucco*, in addition to their individual characteristics, have a number of general similarities that can raise concerns with regards to conservation. Alkalinity and the porous friable nature of these surfaces are particularly important; left untreated they can be somewhat abrasive and create alkaline dust. Coating is probably the best way to prevent efflorescence* and dust problems. Excluding films formed by solvent evaporation (such as shellac and cellulose nitrate), most coatings recommended for wood can be applied to cementitious substrates. Coating a large cementitious substrate such as a concrete floor is more critical than coating a small one such as a mortar joint.

Bricks and stones are not usually alkaline.

Surface Preparation
All masonry should be cured at least 4 weeks to allow optimum formation of hydrated compounds and a decrease in the pH. All cracks and holes should be repaired before coating. Surfaces should be dry (Test 15) and free from all efflorescence, dirt, loose scale, powder, oil, and grease. Gypsumboard needs an emulsion primer (formed by coalescence). Technical data from the manufacturer will indicate whether a coating can be applied directly on to a substrate or if a primer sealer is required (Section 9.1).

New concrete has a glossy finish and the surface must be etched with muriatic acid (a 20–30% solution of hydrochloric acid) so that film will adhere properly. Muriatic acid is a volatile corrosive product and should be used carefully in a well-ventilated area. After treatment, the concrete surface must be thoroughly washed to remove all the acidic solution and allowed to dry completely before the first layer of coating is applied. Sandblasting is not recommended for surface preparation because it is expensive and it generates too much dust.

Old concrete floor is usually altered by interior traffic and needs only to be washed with a trisodium phosphate solution (TSP) before coating.

Airtight and Leaky Enclosures
Coating recommendations are similar to those for wood enclosures, except that films formed by solvent evaporation should not be used.

Walls and Ceilings (Open Enclosures)
With the exception of films formed by solvent evaporation and by oxidative polymerization, there are no specific limitations for the choice of coating.

Floors
Coating recommendations are similar to those for wood floors.

5. Where to Find the Information

The conservation literature has limited information on coatings for display, storage, or packing purposes, and some papers refer to specific brands of coatings that might not be available in different countries or regions, or might have different names. The two main sources of general information about coatings are the technical data and the material safety data sheets. Both can be provided by local dealers or coating manufacturers.

5.1 Technical Data

The technical data provide information about a coating's use and limitations, physical characteristics, shelf life, preparation of the substrate, and nature of the resin; the presence of any alkyd- or oil-based compounds will also be indicated. Unfortunately, the standard test methods from which the data have been obtained may not be specified.

5.2 Material Safety Data Sheets (MSDS)

The MSDS provide information related to safety, but the quality and quantity of information can vary from one company to another. These sheets are easier to get directly from the coating manufacturer than from local dealers.

The "Coating composition" section of an MSDS lists the major components of the coating and indicates those that are hazardous to human health. The forming mechanism of the coating can be inferred from the resin and solvents that are present. Urethane coatings can be identified by the presence of TDI. The presence of pigment extenders (e.g. calcium carbonate) indicates that the coating can absorb acid compounds from the film itself or from the emissive substrate. Formaldehyde may be listed as fungicide* or mildewcide* and should dissipate easily after application of the coating. The presence of acetic acid is unlikely to be indicated in the MSDS.

The "Chemical and physical characteristics" section provides data about the odour, pH (which is generally alkaline for water-based coatings due to the presence of ammonia), and percentage of volatile compounds by volume.

In the "Flammability" (or "Hazardous decomposition products") section, the indicated combustion products provide clues to the composition of a coating. When sulphur (mainly SO_2, H_2S, and H_2SO_4) and chlorinated compounds (HCl) are present, further investigation is necessary to determine their original nature and the impact of the original compounds on objects (Tests 1–9). Carbon monoxide (CO) and dioxide (CO_2) are present in all coatings when burned, and nitrogen oxide compounds (NO_x) are usually present in coatings that contain urethane, amine, or cellulose nitrate resin.

Additional information can be found on the Internet. The "Internet Sites to Consult" section in this document lists sites that provide a large range of information related to coatings; some of them even have an advice centre where experts will answer your questions. Some major paint companies also have a home site that provides useful information on their products, including MSDS.

6. Testing

This section introduces the list of tests described in detail in Appendix 3. These tests can be used to identify or confirm film characteristics, and evaluate their risk to objects. Many of these tests require hazardous substances and a source of heat, so only trained staff should run them and all necessary measures should be taken to ensure safety.

Presence of Specific Volatile Compounds
Test 1. Lead acetate test.
Test 2. Chromotropic acid test.
Test 3. Beilstein test.
Test 4. Glycerol/pH test.
Test 5. Wood acidity test.
Test 6. Diffusion tubes.
Test 7. Chromatographic techniques.

Potential Risk of Damage to Objects Caused by Volatile Compounds
Test 8. Accelerated corrosion test.
Test 9. Photographic activity test.

Physical and Chemical Resistance Tests
Test 10. Chemical resistance of film to liquids.
Test 11. Chemical resistance of film to vapours.
Test 12. Chemical resistance of plastic to vapours.
Test 13. Resistance of film to abrasion.

Tests Related to Film Adhesion
Test 14. Differentiation between emulsion and alkyd films.
Test 15. Moisture content.
Test 16. Film adhesion.

These tests cover a large range of coating characteristics but not all the tests are exclusive and not all of them have to be done. Tables 3 and 4 can be used as tools to facilitate the selection of coatings and the specifications (tests) required. The following pages show examples of Tables 3 and 4 that are filled out for a specific context, but there are clean versions of these two tables in Appendix 4. Table 3 is intended to help define the context of a project and the required coating characteristics, and Table 4 to choose the appropriate tests to ensure the identified requirements are met. These tables can be used as they are or adapted for your own purposes.

The required specifications can be confirmed by an investigation of technical information, MSDS, and testing reports from the manufacturer, with or without the help of a neutral party. When justified, some tests can be carried out to characterize the performance of the film on test samples or prototype coated enclosures; three or four different coatings should be tested for comparative performance and all test samples should be run in triplicate. When coating work is to be contracted out, these performance criteria or specifications, along with the level of performance expected, the tests required, and who will conduct the tests (contractor, manufacturer, or special agency) should be determined in advance and included in the purchase order or request for proposal. If critical decisions on the acceptance of a coating project are to be made on the basis of the verified specifications, the tests should be done by an independent agency such as a conservation institute or a testing laboratory; this will make it easier and less stressful for a client to approve or reject a contract.

CCI can perform most of the physical and chemical tests mentioned in Appendix 3; for advice or more information about these tests and fees, please contact Client Services at:

Canadian Conservation Institute
1030 Innes Road
Ottawa ON K1A 0M5 Canada

tel.: (613) 998-3721; fax: (613) 998-4721
e-mail: cci-icc_services@pch.gc.ca
http://www.cci-icc.gc.ca

7. Mitigation Strategies

Table 5 provides a list of palliative methods for the most common problematic situations. Some methods can be combined with others; levels of success will vary.

8. Coating Project: Check List

Table 6 shows a list of actions, in chronological order, to achieve optimal performance from coatings. The actions listed are not absolute and depend on the nature and size of the project; the number of actions taken can vary. The table also summarizes the key points of this document.

Table 3. Coating selection worksheet.

<table>
<tr><td>Project name
Location</td><td colspan="9"><i>Storage Cabinets (5 units) for the Collection Ferrara, Room 224</i></td></tr>
<tr><td>Substrate</td><td colspan="2">Wood species:</td><td colspan="4">Metal:
✓</td><td colspan="2">Cementitious subst., specify:</td><td>Other, specify:
<i>Gaskets, plastic trays</i></td></tr>
<tr><td rowspan="5">Object(s)
[Consult conservator]</td><td colspan="6">Type:</td><td colspan="3">Sensitivity to volatile compounds (Appendix 1):</td></tr>
<tr><td colspan="6"><i>Mainly silver</i></td><td colspan="3"><i>Suphur (S)</i></td></tr>
<tr><td colspan="6"><i>Bronze</i></td><td colspan="3"><i>High relative humidity</i></td></tr>
<tr><td colspan="6"></td><td colspan="3"><i>Acetic acid (AA)</i></td></tr>
<tr><td colspan="6"></td><td colspan="3"><i>Formaldehyde (F)</i></td></tr>
<tr><td>Airtightness of the enclosure</td><td>Airtight
✓</td><td colspan="4">Leaky</td><td colspan="2">Open (ventilated encl. or room)</td><td colspan="2">Other, specify (such as floor):</td></tr>
<tr><td>Period of use</td><td colspan="3">< 1 year</td><td colspan="4">1–10 years</td><td colspan="2">>10 years ✓ <i>no other use planned</i></td></tr>
<tr><td rowspan="5">Function of the film</td><td colspan="9">Aesthetic (colour, gloss), specify:
<i>white, semi-gloss</i> <i>[Consult Curator/Designer]</i></td></tr>
<tr><td colspan="9">Protect objects from volatile compounds released by the substrate (Tests 4–8), specify compounds of concern:
<i>N/A</i></td></tr>
<tr><td colspan="9">Protect objects from contact with compounds in the substrate (Test 9 or contact test included in Test 9), specify compounds of concern:
<i>N/A</i></td></tr>
<tr><td colspan="9">Protect substrate from compounds released by the objects, fumigants, or any other chemical treatments (Tests 10–12), specify compounds of concern:
<i>N/A</i></td></tr>
<tr><td colspan="9">Protect substrate from abrasion (Test 13): <i>yes for doors, drawers</i>
Provide hard film surface (Test 10): <i>yes: all components</i></td></tr>
<tr><td rowspan="2">Film emissivity and transfer of compounds</td><td colspan="9">Presence or absence of volatile compounds released by the coating that are harmful to objects (Tests 4–8), specify compounds of concern:
<i>sulphur, acetic acid, formaldehyde</i></td></tr>
<tr><td colspan="9">Presence or absence of compounds that can be transferred from the coating to the objects by contact (Tests 1–3 and 9, including contact test), specify compounds of concern:
<i>N/A There will be no contact with the coating</i></td></tr>
<tr><td colspan="5">Resin(s) and film(s)-forming mechanism proposed with respective drying period (Table 1)</td><td colspan="5"><i>-Powder coating; drying period: 1 day</i></td></tr>
<tr><td>Budget for the project</td><td colspan="9"></td></tr>
<tr><td>Budget for testing</td><td colspan="4"></td><td colspan="5">% of project budget:</td></tr>
<tr><td>Special requirements</td><td colspan="9"><i>Gaskets and plastic trays should not contain sulphur, acetic acid and formaldehyde</i></td></tr>
</table>

Table 4. Coating performance specifications.

Specifications (specify coatings/materials if necessary)	**Tests available**		**Tests required**	**Acceptable results**	**Results obtained**	**Tests run by**
Absence of sulphur in test sample ✗	1. Lead acetate test		✓	No sulphur detected		*Staff*
Absence of formaldehyde in test sample ✗	2. Chromotropic acid test		✓	No formaldehyde detected		*Lab*
Absence of chloride in test sample	3. Beilstein test			No chloride detected		
Absence and level of acid volatile compounds released by test sample/enclosure	4. Glycerol/pH test			No difference in pH between the test sample/enclosure and the blank		
Low acidity of the wood	5. pH measurement			pH > 5		
Absence of various volatile compounds released by test sample/enclosure *from the cabinets before delivery*	6. Diffusion tubes	*AA*	✓	No more than CL, BL, or level specified for each volatile compound◇, specify: *must be below the limit of detection of the tubes*		*Manufacturer*
		F	✓			
	7. Chromatographic techniques					
Absence of corrosive volatile compounds released by test sample ✗	8. Accelerated corrosion test with silver, copper, lead coupons or others	Ag	✓	No corrosive volatile compounds		*Lab*
		Cu	✓			
		Pb	✓			
Absence of compounds reactive to photographic test sample with contact	9. Photographic activity test with colloidal silver and stain detectors			Coll. silver: ΔDAg<20%		
				Stain: ΔDgel<0.08		
Absence of compounds reactive to test sample with contact	9. Contact test			No change		
Hard film	10. Pencil test		✓	>4H	*pass* ✗✗	
Chemical resistance of test film to different liquids	10. Pencil test			>2H after 2 min >4H after 24 h + 24 h		
Chemical resistance of test film to different vapours	11. Vapour exposure test			>4H		
Chemical resistance of plastic such as gasket to different vapours	12. Incubation test			No change		
Resistance of film to abrasion	13. Taber Abraser		✓	Weight loss ≤100 mg	*pass* ✗✗	
Specifications for the quality of the coating application						
Film adhesion	14. Identification of previous coating and patch test			Must be compatible		
	15. Moisture content			Moisture content ≤15%		
	16. Tape test		✓	No detachment (5B)		*Staff*
Dry film thickness	Coating thickness gage			≥0.13 mm (≥5 mil)		

Comments on test results

✗ *Test coatings, gaskets and plastic trays.*

✗✗ *Results for tests 10 and 13 are confirmed by technical data.*

◇ For control levels and background levels see Appendix 2.

Table 5. Mitigation strategies.

Situation	Recommendations◊	Details/limitations
Coating a room without removing objects	Avoid any films formed by oxidative polymerization and urethanes formed by moisture-cured or catalysed polymerization.	These films can release high levels of volatile compounds that are harmful to objects (Sections 3.3–3.5).
	Wrap objects.	Must be well sealed.
	Increase ventilation in the room.	Increase fresh air intake or use fans for at least 4 days (Section 9.5).
Liquid coating drops on an object	Call a conservator immediately.	Do not try to remove by yourself.
Observation of efflorescence and discoloration on objects	Remove objects from this area and contact a conservator.	Determine the source of pollution.
Generation of dust from a coated surface by friction	Wrap the object in storage.	Wrap with acid-free paper, textile, Mylar (Melinex) sheets, or polyethylene sheets. Fix the problem, inform staff of handling problem, and avoid overloading drawers (Section 2.1).
High level of volatile compounds (smelly) in airtight or leaky enclosures	Extend the drying period.	Dry at least 4 weeks before objects are introduced.
	Increase ventilation.	Make holes or increase gaps; infiltration of dust, pollutants, and insects may increase.
	Reduce RH.	Use silica gel [18] or portable mechanical devices [19, 20]; do not reduce RH during the drying period of moisture-cured urethane (Section 3.4).
	Use absorbent materials.	Use activated charcoal or potassium permanganate-impregnated alumina.
If the volatile compounds originate from an emissive substrate	Apply extra layers of coatings.	Extra layers increase the barrier property of a film [21].
High level of volatile compounds (smelly) in an open enclosure or room	Extend the drying period.	Dry at least 4 days before objects are introduced.
	Increase ventilation in the room.	Increase fresh air intake of the heating, ventilating, and air-conditioning systems (HVAC) or use fans.
	Reduce RH in the room.	Use portable mechanical devices [19, 20] or HVAC.
After being enclosed in the presence of an emissive film, porous objects remain smelly for a long time after removal (Section 9.6)	Use ventilation.	Ventilation may be necessary for a period equivalent to the contamination period.
	Place smelly object in a new enclosure with absorbent materials.	Not as efficient as ventilation but isolating the smelly object can be convenient.

◊ For more recommendations and details see [22].

Table 6. Coating project check list.

Stage	Actions
Definition of the context	Define the purpose of the enclosure/room (display, storage, transportation; also aesthetic, protective, period of use). Determine the nature and sensitivity of the objects that will be enclosed. Define the substrates and the degree of leakage of the enclosure/room. Determine what physical and chemical properties the coating must have (Tests 1–13; in section "Acceptable test results"). Consult Tables 3 and 4.
Selection of the coating	Consult reputable coating companies. Specify the resin, the film-forming mechanism, and the drying period according to the parameters above and Sections 2–4. Avoid choosing brand new coatings without seeing results of long-term performance (>3 years). Ask for the technical data, MSDS, and any report on film performance (Section 5). If necessary, ask for coating samples and coated substrate samples to test physical and chemical properties of the film.
Receipt of the coating	Indicate the date on the cans of coating. Do some spot tests to determine the presence of pollutants in the coating (Table 4). Test the physical and chemical properties of the coated substrate samples (Table 4).
Before coating	Substrates must be dry (Test 15). For wood product substrates, verify the absence of urea-formaldehyde adhesive. Move objects outside of the working area or cover them carefully (Section 2.1). Follow the manufacturer's instructions; the rule for recoating is that previous finishes must be clean, dry, dull (for varnishes), and compatible with the new film (Sections 4 and 9.1), e.g. films formed by coalescence need a primer if the previous film is not formed by the same mechanism or if it is not made with the same resin (Test 14).
During coating	Ensure moderate ventilation for the first 3 h after coating application, then the ventilation can be increased (Section 9.5). Ensure adequate mixing and proper ratio of coating components when appropriate (Sections 2.1 and 3.5). Apply multiple thin coats rather than a single thick coat; the general rule for bare substrate is one layer of primer and two topcoats, although clear films formed by solvent evaporation or by coalescence will need more layers (Section 3.1). If sanding is required between layers of coating, use a #320 grit sandpaper◊. Wooden edges need additional layers. Inspect and approve coated surfaces just prior to each new coat; for large-scale projects, this inspection should be done by an architect or engineer.
After coating	*If the work is done by a contractor from outside of the museum, the two first actions should be done at the factory or by independent experts before shipping.* Verify the chemical and physical properties of the control samples☐ (Table 4); if the properties are not similar to what was requested, inform the client and the contractor. Respect the drying period. If this is not possible, ensure that levels of harmful volatile compounds are acceptable (Table 4) before moving objects into the newly coated enclosure; if levels are too high, use mitigation strategies (Table 5). Use volatile compound monitors (Tests 7 and 8, normal corrosion test) and regularly inspect the monitors and objects in any enclosure for any trace of deterioration. Record the trade name of the coating and all the specifications for future coating work, or for premature film failure.

◊ If the grit is #80 or less, it is possible the scratch marks will show through the next layer of coating; if the grit is too fine, the sandpaper will plug up.

☐ Control samples must be coated with the same batch of coating that will be used for the rest of the enclosures or substrates.

9. Miscellaneous

9.1 Primers

Primers provide maximum adherence to a substrate and serve as a foundation for the application of topcoats. There are four main types of primers:

Primer Sealer: used mainly to seal porous surfaces such as new gypsumboard or new plaster.

Undercoat: used to seal, build, and level a surface (usually new woodwork) as it is coated; easy to sand.

Specialty Primer: used to solve spot-priming problems, e.g. over a grease stain or knot to prevent bleeding through the topcoat.

Metal Primer: used to inhibit rust as well as improve adherence.

Some coatings do not require a primer; the topcoat can simply be diluted with the main solvent of the coating. Other coatings need specific primers compatible with the topcoat, although the primer may or may not be formed by the same mechanism as the topcoat. It is imperative to respect the primer proposed by the manufacturer of a coating; any substitution must be approved by them. Primers formed by oxidative polymerization are not recommended for airtight and leaky enclosures, although baked primers formed by this mechanism are acceptable.

9.2 Previously Coated Surfaces

A previously coated surface must be free of contaminants before it can be recoated. Surfaces should be cleaned with detergent, cleaning products such as trisodium phosphate (TPS), or water. Varnishes or glossy surfaces should be lightly sanded (#320 grit) to obtain a dull finish. Rubbing the previously coated surface with a wet rag of denatured alcohol (Test 14) will determine if the old film is an emulsion or an alkyd.

9.3 Fire Retardants*

The flammability of a film depends on the nature of its components. There are several standard methods to evaluate the performance of films under fire conditions; the common specification is to have a flame spread rating* less than 25 (Class I or A) [23]. There is little choice on the market for fire-retardant coatings, but good local dealers can make suggestions for appropriate selections.

Fire-retardant films that release ammonia or inorganic acids (such as phosphoric acid) when heated should not be used inside airtight or leaky enclosures; instead, a good vapour barrier film such as two-part epoxy on treated fire-retardant wood is recommended. In a situation of localized fire, the treated film and treated wooden panels on the outside of the enclosure will slow down the fire development, and the fire-retardant components released by heating will be blocked by the (regular) film used inside the enclosure.

9.4 Gloss

Flat films are usually preferred for exhibition purposes; they do not show surface irregularities or cause distracting reflections, but are not very washable and tend to abrade easily. Gloss films are more durable and do not mark easily even when there is considerable human traffic, but tend to enhance texture or defects in the surface. Films with a patina or pearl finish are a compromise between aesthetics and durability.

9.5 Vapour Barrier Property

The vapour barrier property of a film depends on factors such as the coating components and the film-forming mechanism. For example, films formed by catalysed polymerization are better vapour barriers than films formed by coalescence or solvent evaporation. The pigment-resin ratio of a film also plays a role in the barrier effect; glossy films have a lower pigment content than flat films and are less permeable. The presence of thin plate-like extender pigments such as mica and aluminum flake can increase the impermeability of a film.

Ventilation is necessary for safety and health considerations, but can influence the vapour barrier property of a film. Limited ventilation in the early drying stage provides for optimal cross-linking during the polymerization process whereas the opposite is true for coalescence. Most films formed by coalescence contain a co-solvent, which is a slow evaporating solvent like diethylene glycol monobutyl ether that assists in fusing the emulsion particles together. Limited ventilation may result in high levels of water vapour, in which case most of the co-solvent will evaporate from the film before the water; this will result in a poorly coalesced and more permeable film. Too much ventilation in the first few hours will cause all types of film to form too fast, without the proper density. Moderate airflow during the first few hours is a compromise that will maximize safety and the film-forming properties of a coating application on an interior surface. Due to the toxicity of TDI, even in a very low concentration (0.02 $\mu g/m^3$), the application of a urethane coating must be done using an exhaust fan and mask respirators.

9.6 VOC* Regulation, Odour, and Museum Concerns

The coating industry, in an effort to reduce the impact of volatile organic compounds (VOCs) on human health and the environment, tends to use low-density solvents and high solid contents in their formulations. Increasing the solid content of a coating formulation normally reduces the emission of VOCs during the early stages of the film-forming process. This correlation has been observed for freshly applied films formed by catalysed or oxidative polymerization, but no relationship has been found between solid content and the emission of VOCs after a few weeks of drying. Also, high solid content may cause early failure (cracking, flaking) of a film due to decreased penetration into porous surfaces, reduced adherence, and impaired vapour barrier properties.

Unpleasant smells have been reported for enclosures coated with films that emit organic solvents (such as all those formed by polymerization), especially if drying periods have been shorter than those recommended in this document (Table 1). This is also a problem with coated airtight enclosures that have been kept closed for several months. For films formed by moisture-cured and catalysed polymerization, prepared and applied in optimum conditions, the reactive components of the film should be completely consumed within 4 days, and the VOCs or solvents released after that time should not be harmful to objects. However, porous objects (such as paper, wood, textile, skin, etc.), mounts, and enclosure materials will absorb the VOCs released by a coated airtight enclosure. Depending on the freshness of the film, the length of the contamination period, and their porosity and thickness, these objects and materials can remain smelly for a long period after being removed from the emissive enclosure. The best way to minimize the problem is to follow the advised drying period and, if possible, use coatings that form by coalescence rather than coatings with organic solvents; some mitigation strategies shown in Table 5 can also be taken.

Internet Sites to Consult

Canadian Conservation Institute:	www.cci-icc.gc.ca
MSDS:	msds.pdc.cornell.edu
Paint Info:	www.paintinfo.com
The Paint Research Association:	www.pra.org.uk/index.htm
Paint Store:	www.paintstore.com
Protective Coatings Worldwide:	www.protectivecoatings.com

Documents to Consult

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Glossary

Abrasion resistance
Coating cannot be worn away by rubbing or friction; a matter of toughness rather than hardness, and a necessary quality for floor finishes, enamels, and varnishes.

Acid-sensitive object
Item that is known to be altered in the presence of acidic volatile compounds.

Adsorption/reaction material
Substance that can adsorb and/or react with compounds; in a dry environment, adsorption of volatile compounds is more common than reaction with them.

Air exchange rate
Pace of airflow through a space or enclosure, usually expressed in terms of room or enclosure volume units per unit of time.

Alkyd
Synthetic resin that forms a film by oxidative polymerization.

Autocatalytic reaction
Process accelerated by one of its own products.

Catalysed polymerization
Cross-linking of two different components, usually in the presence of accelerators or cross-linking agents (the catalysts), which may or may not enter into the reaction and become part of the cross-linked system; does not require an external agent.

Catalyst
Compound that increases the rate of a reaction.

Change-of-phase
Formation of a film after application of fluid or dry powder (electro deposition) followed by heating; also called heat fluxing.

Coalescence
Formation of a film by evaporation of water from an emulsion, permitting contact and fusion of adjacent resin droplets; tends to produce a porous film.

Coating
Liquid or solid that is converted to a solid protective, decorative, or functional adherent film after application as a thin layer; generic term for paints, varnishes, lacquers, enamel, etc.

Cross-linking
Setting up of chemical bonds between the chains of a polymer molecule to form a three-dimensional structure; it generally toughens and stiffens films, and reduces solubility.

Dry oil or dry oil-based compound
Oil that possesses the ability to take up oxygen from the air and form a film by oxidative polymerization.

Drying period
Amount of time a liquid coating needs to change into a solid film; dryness can be related to the dry-to-touch feel, the non-tacky surface (dry-hard), or the readiness for recoating. When chemical reactions are involved, the term curing period can be used to refer to the time required to form a coated film. Drying period is defined in this document as the time required to reach an evolution of volatile compounds such that steady-state concentrations in the enclosure or room will be acceptably low.

Dry-hard
Any mark left by thumb, exerting maximum downward pressure on a film, is completely removed by a light polishing with a soft cloth.

Dry-to-touch
Film will not transfer onto an item touched lightly against it.

Efflorescence
Growth of a fibrous or powdery alteration product on a surface or an encrustation of soluble salts deposited on the surface usually caused by salts or free alkalies leached from cementitious substrate as moisture moves through it.

Emulsion (or latex)
Two-phase liquid system in which small droplets of one liquid are immiscible in and dispersed uniformly throughout a second continuous liquid phase.

Enamel
Coating that is characterized by the ability to form an especially smooth and hard film.

Enclosure
Collection of materials that surrounds a limited space.

Equilibrium concentration
Maximum strength that a volatile emitted from a material can reach in absolute airtight enclosure; the emission and the absorption rate of the volatile are equal.

Extender pigment
Inorganic material in powder form that has little hiding power; incorporated in coatings to adjust gloss, reduce cost, or for other specific reasons depending upon the intended use of the coating.

Film
Layer(s) of coating covering a surface.

Flame spread rating
Number or classification indicating a comparative measure derived from observations made during the progress of the boundary of a zone of fire under defined testing conditions.

Fibreboard (or insulation board)
Panel manufactured from lignocellulosic fibres combined with a synthetic resin or other suitable binder; it has a density not greater than 400 kg/m^3.

Fire retardant
Descriptive term implying that the described product will significantly reduce the rate of flame spread on the surface of a material to which it has been applied, resist ignition when exposed to high temperatures, or insulate a substrate to which it has been applied thereby prolonging the time required for the substrate to reach its ignition, melting, or structural-weakening temperature.

Funcigide
Chemical agent that stops, retards, or prevents the growth of fungi or spores.

Gloss
Property of a film surface to reflect light in a mirror-like manner (specular reflection); the following ranges, in increasing order of gloss, are generally used: flat (matte), eggshell, satin, semigloss, and high gloss.

Gypsumboard
Sheet or slab having an incombustible core, essentially gypsum, surfaced with paper suitable to receive decoration.

Hardboard
Wood-fibre consolidated under heat and pressure to a density of 800–1200 kg/m^3; commonly found under the name Masonite or Isorel.

Hiding power
Ability of a film to conceal or obscure a surface over which it has been uniformly applied.

Lacquer
Coating based on synthetic resin forming a film, or natural material dissolved in organic solvent that dries primarily by solvent evaporation; typically based on nitrocellulose, other cellulose derivatives, vinyl resins, acrylic resins, shellac, etc.

Latex
See Emulsion.

Liquid coating
Fluid that is converted to a solid protective, decorative, or functional adherent film after application as a thin layer.

Mildewcide
Chemical agent that destroys, retards, or prevents the superficial growth produced by fungi on various surfaces.

Moisture-cured polymerization
Reaction of water vapour from the atmosphere with an isocyanate group, usually tolylene diisocyanate (TDI), to form urea linkages; the only film formed by this mechanism is moisture-cured urethane.

Museum
Used in a general sense in this document to include galleries, archives, historic sites, etc.

Object
Used in a general sense in this document to include works of art, artifacts, books, manuscripts, specimens, and other objects of natural, historical, or archaeological origin.

Open grain (coarse-textured)
Classification for woods having large pores; as opposed to close grain (fine-textured).

Oxidative polymerization
Autoxidation of non-conjugated unsaturated fatty acid components in alkyd (or oil) resins forming conjugated hydroperoxides, which break down to radicals and then promote polymerization by cross-linking reactions.

Oxidant-sensitive object
Item that is known to be altered in the presence of oxidizing compounds such as ozone and peroxide.

Paint
Pigmented liquid, applied in a thin layer, that is converted to a solid film.

Plaster
Paste-like material, usually a mixture of Portland cement, lime, or gypsum with water and sand.

Pollutant
Gaseous, liquid, or solid compound that can damage objects.

Polymer
High-molecular-weight material composed of a large number of repeat monomer units linked together.

Polymerization
Reaction of single molecules (monomers) to form a polymer.

Primer
First coating applied to a substrate; designed to provide adequate adhesion to new surfaces and formulated to meet special requirements, e.g. anti-corrosive pigments for metallic surfaces.

Resin
Solid or semi-solid organic material of either natural or synthetic origin.

Solid content
Amount of non-volatile matter in a coating composition, i.e. the ingredients that, after drying, are left behind and constitute the dry film.

Solvent evaporation
Liquid vaporization that occurs after a coating is applied, leaving a dry film of unchanged resin.

Stain
Solution or suspension of colouring matter in a vehicle, designed to colour a surface by penetration without hiding it or leaving a continuous film.

Steady-state concentration
Volatile accumulation in enclosure resulting from the summation of different parameters involved in the transfer of volatile compounds such as emission rate, air exchange rate, and absorption rate.

Stopper (wood putty)
Pigmented products used for filling cracks and indentations to obtain a smooth, even surface.

Stucco
Composed of Portland cement, lime, and sand, which are mixed with water (simulated stucco can be composed of epoxy as a binder); usually textured.

Substrate
Any surface to which a coating is applied.

Tempered hardboard
Wood-fibre panels denser than hardboard, with improved strength properties and resistance to water; drying oil such as linseed oil or tung oil is introduced in the surface before pressing.

Thermoset
Infusible polymer that becomes highly cross-linked and solidified into a hard mass when heated.

Threshold limit value (TLV)
Maximum concentration of a volatile compound to which most workers could be repeatedly exposed, day after day, without adverse effect.

Topcoat (finish coat)
Coating intended to be the last one applied in a coating system; usually over a primer or an undercoat.

Undercoat
Coating that seals, builds, and levels a surface (usually new woodwork); improves the seal and serves as a base for the topcoat, for which it provides better adhesion.

Varnish
Liquid composition, applied in a thin layer, that is converted to a transparent solid film.

Volatile compound
Component of coatings (or any materials) that evaporates easily.

Volatile organic compound (VOC)
Class of chemical mixtures that contain one or more carbon atoms and tend to evaporate at room temperature.

Wood filler
Pigmented product formulated primarily to fill the grain of wood prior to the application of undercoats.

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Appendix 1. Objects that are vulnerable to volatile compounds in coatings and substrates

Notes: The damage caused by compounds that is reported in the literature is not necessarily specific to coatings, but damage from coatings should be similar. Also, because many compounds can be present in the same environment their damaging effects can be synergistic. ▣: Severe exposure indicates conditions such as elevated volatile concentration, RH, and temperature, as well as industrial environments or immersions. ✚: Moderate exposure indicates volatile compounds released by materials in mild conditions in the laboratory or in situ; materials reported to cause damage in moderate exposure are not repeated in severe exposure. [—]: There is no information in the literature related to this compound. When a reference is not specified refer to [24].

Objects	**Severe Exposure ▣**	**Moderate Exposure✚**
Metals	**Metal objects can become tarnished or corroded in the presence of these compounds**	
Aluminum	ammonia, formaldehyde [25], formic acid, hydrochloric acid, and hydrogen sulphide	
Brass	acetic acid [26], acetic anhydride, hydrochloric acid, hydrogen sulphide, and phosphoric acid	formaldehyde [27]
Bronze	amines	acetic acid [28, 29] and formaldehyde [27]
Cadmium	acetic acid [26, 30]	
Copper and alloys	acetates [31], acetic acid [26], amines [31, 32], ammonia [30], formaldehyde [25], formic acid, peroxides, and phosphoric acid	sulphur compounds [33]
Iron and alloys	acetaldehyde, acetic acid [26, 30], amines, ammonia, carbon disulphide [31], fatty acids, formic acid, hydrochloric acid, peroxides, and phosphoric acid	
Lead	acetic anhydride, fatty acids, formic acid, and peroxides	acetic acid [34] and formaldehyde [27]
Magnesium	acetic acid [26, 30]	
Nickel	phosphoric acid	
Silver	formaldehyde [25, 35]	sulphur compounds [13, 33]
Zinc	acetic acid [26, 30, 34] and formaldehyde [25, 35]	cellosolve acetate [36]
Natural objects	**Natural objects can become stained, discoloured, brittle, weak, or form efflorescence products on their surface in the presence of these compounds**	
Calcium-based objects (shells, coral, limestone, ulexite...)	acetic acid [37] (for bones)	acetic acid [28, 38–42] and formaldehyde [40–42]
Cellulose	acetic acid [43]	fatty acids [—] and sulphur compounds [—]
Ceramics		ammonia [44]
Dyed cotton		nitrogen oxide(s) [45]
Lead pigment	formaldehyde [25] and hydrogen sulphide [—]	
Pigments, dyes, linseed oil (general)	alkaline dust [47]	
Rubber	acetates	
Silk	alkaline dust [47]	nitrogen oxide(s) [45]
Textile (general)	butylated hydroxytoluene [48] and sulphur dioxide [49]	nitrogen oxide(s) [50]
Vegetable-tanned leather	sulphur dioxide [—]	
Verdigris	formaldehyde [25]	

Objects	Severe Exposure ▣	Moderate Exposure✚
Synthetic objects	**Synthetic objects can become discoloured, brittle, or weak in the presence of these compounds**	
Acrylic	acetates, formic acid, and toluene	
Cellulose acetate (CA)	acetates, formaldehyde, hydrochloric acid, nitrogen oxide(s) [52], and phosphoric acid	acetic acid [53]
Cellulose nitrate (CN)	acetates and phosphoric acid	nitrogen oxide(s) [—]
Chloroprene and neoprene	acetic acid, amines, fatty acids, formaldehyde, peroxides, phosphoric acid, sulphur dioxide, and toluene	
Epoxy	acetic acid, carbon disulphide, ethyl acetate, formic acid, nitrogen oxide(s), and peroxides	
Ethyl acetate	formaldehyde	
Nitrile	acetic acid	
Nylon	acetic acid, formic acid, hydrogen sulphide, peroxides, and phosphoric acid	
Plastic (general)		tolylene diisocyanate [51]
Poly(vinyl chloride) (PVC)	acetaldehyde, acetates, acetic anhydride, amines, and toluene	
Poly(vinylidene chloride); Saran (PVDC)	ammonia	
Polyethylene (PE)	acetates, acetic acid, acetic anhydride, fatty acids, and toluene	
Polypropylene (PP)	peroxides, sulphur dioxide, and toluene	
Polystyrene (PS)	acetates, acetic acid, ammonia, fatty acids, formaldehyde, peroxides, and toluene	
Polyurethane (PU)	acetic anhydride, amines, ammonia, formic acid, and hydrogen sulphide	
Rubber	acetates	
Silicone	acetates, formaldehyde, and toluene	
Miscellaneous	**These objects can become stained, discoloured, brittle, or weak in the presence of these compounds**	
Colour micrograph films	sulphur dioxide [46]	
Dyes from colour photography	hydrogen sulphide [46]	peroxides [54], acetic acid [55], and fatty acids [—]
Hair of the hygrometer	alkaline dust [47]	
Newsprint	formaldehyde [25]	
Organic and inorganic objects	sulphuric acid [—]	
Organic and inorganic pigments	nitrogen oxide(s) [46, 56, 57]	
Porous objects		dust [—]

Appendix 2. Volatile compounds in coatings and substrates

Notes: Concentrations are given in mg/m^3 and in (ppm); unit conversion: X ppm = Y mg/m^3 x (24.04/molecular weight). □: Control levels (CL) are the maximum concentrations of compounds allowed in conservation; most compounds do not have widely accepted conservation control levels. ∇: When the CL is not specified, background levels[1] (BL) can be used as the allowed concentration. ☆: Threshold limit value* (TLV) refers to the safe limit for human exposure and in the absence of precise allowable limits for conservation it may be a wise first step to ensure safety for staff; most TLV data are from the MSDS provided by distributors or from [58].

Volatile compounds	**Origin**		**Molecular weight (g/mol)**	**Control level □**	**Background levels ∇**	**Threshold limit value ☆**
Acetates (CH_3CO_2R)	- as solvent or additive in some films formed by catalysed polymerization, films formed by oxidative polymerization, films formed by coalescence, and vinyl films formed by solvent evaporation [36,59] - in the presence of water and acids it can be hydrolysed to acetic acid [60]	cellosolve acetate	130.13			27 (5)
		ethyl acetate	88.09			1400 (400)
Acetaldehyde (CH_3COH)	- films formed by oxidative polymerization [61] - wood products - can be transformed into acetic acid by Cannizzaro reaction [62]		44.05		0.007 (0.004) [63]	46 (25)
Acetic acid (CH_3COOH)	- films formed by oxidative polymerization and urethane films formed by catalysed polymerization [1] - free in films formed by coalescence [64] - deterioration of vinyl acetate films formed by coalescence [65] - wood products [1] and acetylated wood [66]		60.05		0.01 (0.005) [63]	25 (10)
Acid anhydrides ($(RCO)_2O$)	- hardener in epoxy films formed by catalysed polymerization - can be transformed into an acid by hydrolysis [60]	acetic anhydride	102.09			21 (5)
Amines (NH_2R)	- epoxy and some urethane films formed by catalysed polymerization - some films formed by coalescence [67]					
Ammonia (NH_3)	- films formed by coalescence and films formed by catalysed polymerization + coalescence; it maintains a high pH to ensure optimum stability of the emulsion (0.01–1.5% v/v) [67] - concretes [68]		17.03		0.0007 (0.001) [69]	18 (25)

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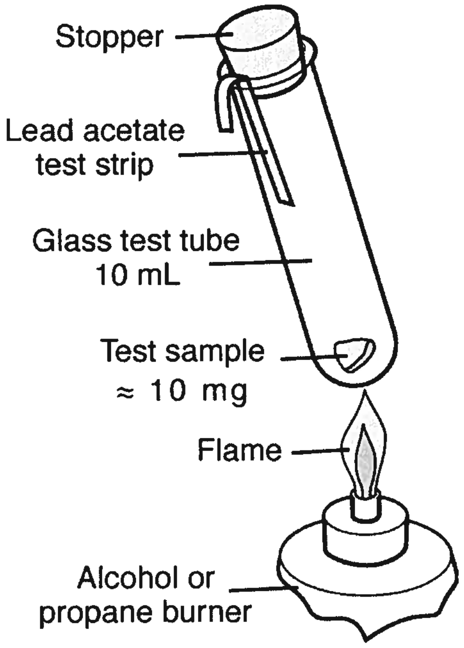
[1] Amounts of pollutants present in the outdoor environment due to natural sources.

Volatile compounds	**Origin**	**Molecular weight (g/mol)**	**Control level □**	**Background levels ∇**	**Threshold limit value ☆**
Butylated hydroxytoluene (BHT) ($[C(CH_3)_3]_2 CH_3C_6H_2OH$)	- used as an antioxidant in some epoxy films formed by catalysed polymerization and some cellulose nitrate films formed by solvent evaporation	220.04			10 (1)
Dust, particles	- alkaline dust from uncoated concrete - acidic dust from uncoated wooden structures		0.075 [70] or ≥30% prefilter, ≥80% intermediate, and ≥90% fine filter based on ASHRAE atmospheric dust spot efficiency [73]		
Fatty acids: carboxylic acids with more than 3 carbons (RCOOH)	- films formed by oxidative polymerization [1, 61] - wood products			0.01	
Formaldehyde (HCOH)	- fungicides or mildewcides in films formed by coalescence [67] - urea formaldehyde in some films formed by catalysed polymerization [59, 72] - decomposition of hexaoxatricosane in films formed by coalescence[67] - formaldehyde-based glue in wood products [72, 73] - can be transformed into formic acid by Cannizzaro reaction [62]	30.05		0.006 (0.005) [63] 0.001 (0.0008) [74]	0.4 (0.3)
Formic acid (HCOOH)	- films formed by oxidative polymerization [61]	46.03		0.001 (0.0005) [74]	10 (5)
Hydrochloric acid (HCl)	- decomposition of chlorinated additives or chlorinated films formed by solvent evaporation [30] - catalyst in some formaldehyde-free wood products [75] - acid etching treatment for concrete	36.46			8 (5)
Nitrogen oxide(s) (NO_x)	- decomposition of urethane films - decomposition of cellulose nitrate films - mainly outdoor sources nitrogen dioxide (NO_2)	46.01	0.005 (0.001) [70] 0.01 (0.005) [71]	0.0002 (0.0001) [69, 74]	
Peroxides (ROOR)	- films formed by oxidative polymerization [54, 76] hydrogen peroxide (H_2O_2)	34.01		0.001 (0.0007) [74]	1.4 (1)
Phosphoric acid (H_3PO_4)	- some flame retardant agents	98.00			1 (0.2)

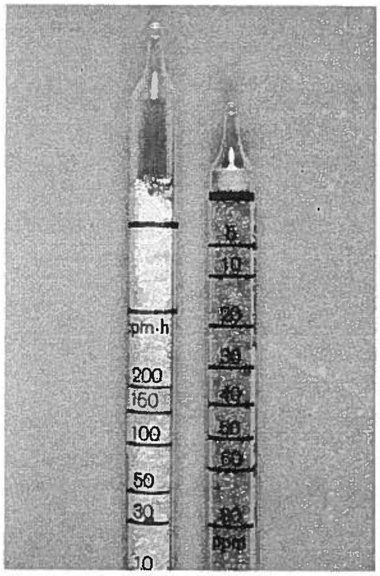
Volatile compounds	**Origin**		**Molecular weight (g/mol)**	**Control level □**	**Background levels ∇**	**Threshold limit value ☆**
Sulphur compounds	- oil-based film petroleum-derived solvent [13] - surfactant such as sodium dioctyl sulfosuccinate used in some films formed by coalescence [67] - lithopone pigment and colloid casein in films formed by coalescence [13] and films formed by oxidative polymerization [13, 77] - hardener (sulphuric acid) for acid-cured films formed by catalysed polymerization [64] - some films formed by oxidative polymerization that have been sulphonated (possible) [78] - mainly outdoor sources	carbon disulphide (CS_2)	76.13		0.00009 (0.00003)	32 (10)
		sulphur dioxide (SO_2)	64.06	0.001 (0.0004) [70] 0.01 (0.004) [71]	0.0003 (0.001) [69, 74]	5 (2)
		hydrogen sulphide (H_2S)	34.08		0.0001 (0.0001) [74]	14 (10)
		sulphuric acid (H_2SO_4)	98.08			1 (0.3)
Toluene ($C_6H_5CH_3$)	- solvent in some films formed by oxidative polymerization and films formed by catalysed polymerization		92.15			192 (50)
Tolylene diisocyanate (TDI) ($C_6H_6CH_3\cdot 2(NCO)$)	- mainly urethane films formed by moisture-cured polymerization but can be found in lower levels in urethane films formed by catalysed polymerization and films formed by oxidative polymerization [79]		174.15			0.02 (0.005)
Volatile organic compounds (VOCs)	- all films formed from liquid coatings		the nature and reactivity of all components are not always known so caution is required when VOCs are present in large quantities			
Water (H_2O)	- films formed by coalescence		18.01	increases in relative humidity aid deterioration processes such as hydrolysis, corrosion, efflorescence, and fungus activities		
Xylene ($C_6H_4(CH_3)_2$)	- solvent in some films formed by oxidative polymerization and films formed by catalysed polymerization		106.17			442 (100)

Appendix 3. Testing procedures

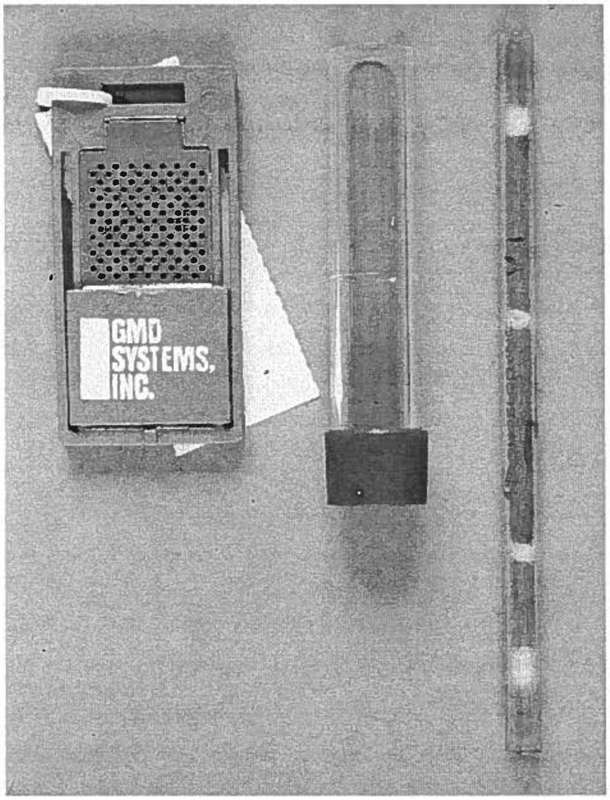
Test 1	**Lead Acetate Test**
Purpose of test	To determine the presence of sulphur. Films or materials containing sulphur compounds are known to discolour, corrode, and weaken some objects (see Appendix 1).
Sample preparation	Liquid samples should be dried on aluminum foil for 1 day; solid samples such as a gasket need no preparation.
Reagents to be used	Lead acetate strip dispenser: BDH Chemicals, 350 Evans Avenue, Toronto ON M8Z 1K5. Hydrogen peroxide 3–10% solution: available at any local drugstore.
Comments	The procedure should be carried out as follows: Wet the lead acetate test strip with one or two drops of clean water. Put the wet strip and a small test sample in a glass tube as shown in Figure 3; the test strip and sample should not be in contact. Use a flame to pyrolyse the sample in the glass tube; tilt the tube flat during pyrolysis to make sure the dense smoke reaches the test strip. The test strip will turn brown in the presence of sulphur. Remove the brown test strip from the glass tube and add one drop of hydrogen peroxide. The presence of sulphur compounds in the sample will be confirmed if the brown test strip turns white. This test can produce strong irritant odours and should be conducted under a fumehood. Figure 3. Schematic representation of the lead acetate test. 
Acceptable test results	The film or material should not be used if the test strip turned white after being stained during pyrolysis. Films or materials such as vulcanized rubber containing sulphur should not be used in contact with objects and should not share the same airtight or leaky enclosure. Alternative test: Azide test [80].

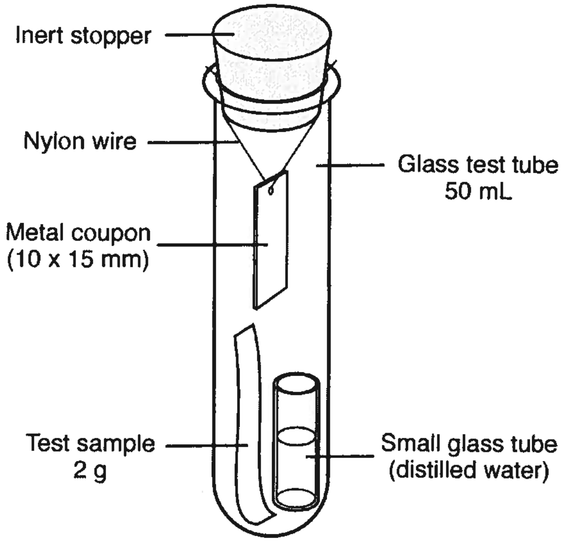
Test 4	**Glycerol/pH Test**
Purpose of test	To determine the acidity of volatile compounds. Films or materials containing acid compounds are known to discolour porous objects and corrode metal objects.
Test methodology	Tétreault, J. "La mesure de l'acidité des produits volatils" [21].
Sample preparation	In a test chamber, liquid samples should be dried on aluminum foil for the recommended period (Table 1); solid samples such as a gasket need no preparation.
Reagents to be used	pH strips (pH range 4.0–7.0): Sigma-Aldrich Canada Ltd., 2149 Winston Park Drive, Oakville ON L6H 6J8. Glycerol (glycerine): available at any local drugstore.
Comments	Saturate a pH strip with one or two drops of a solution of 20 mL water and 80 g glycerine. Volatile compounds will accumulate on the strip and the colour will change based on the quantity and nature of the acids absorbed. The initial pH should be at least 6. Place a test sample of at least 2 g in a 250-mL (or smaller) glass jar with a pH strip for 24 h; place a pH strip in a similar jar without a sample as a control (blank). For a coated enclosure/room, place pH strips in the enclosure and outside (in "clean" environment) (blank). Avoid any contact between the impregnated pH strip and the test sample or enclosure. The date of coating application and the date of analysis must be specified.
Acceptable test results	For a film or material to be acceptable, no difference in the pH value should be observed between the pH strip in the jar (or in the enclosure) and the blank. Overall volatile compounds released by films formed by coalescence are usually alkaline due to the presence of ammonia and should evaporate in few days. Some volatile compounds (such as peroxide which bleaches the pH strips) can interfere with the test. Alternative tests: Iodide-iodate test [81] (for small samples only), and Tests 6 and 7.

Test 5	**Wood Acidity Test**
Purpose of test	To determine the acidity of wood. Acid wood species are known to corrode metal objects.
Test methodology	Carroll, M.N., L.P. Clermont, and G. Leblanc. "pH and Buffer Capacity of Canadian Woods in Relation to Particle Board Manufacture" [6].
Sample preparation	Rasp the wood sample.
Reagents to be used	Distilled water (pH no less than 6.3).
Comments	Place 5 g of wood sample into 100 mL of distilled water. Agitate the mixture with a magnetic stirrer for 2 h. Measure pH.
Acceptable test results	As a rough rule, woods of pH less than 4.0 are likely to be highly corrosive, and those of pH more than 5.0 should be suitable. Consult Table 2 for pH values of different wood species. Alternative tests: Tests 4, 6, and 7.

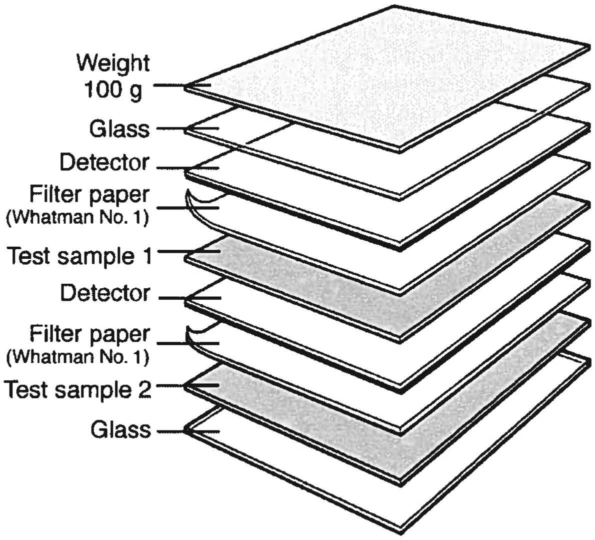
<table>
<tr><td>Test 6</td><td>Diffusion Tubes</td></tr>
<tr><td>Purpose of test</td><td>To determine the specific volatile compounds released by a sample. Appendix 1 provides information on the harmful effects of various volatile compounds.</td></tr>
<tr><td>Test methodology</td><td>Leichnitz, K. “Detector Tube Handbook: Air Investigations and Technical Gas Analysis with Dräger Tubes” [84].</td></tr>
<tr><td>Sample preparation</td><td>In a test chamber, liquid samples should be dried on aluminum foil for the recommended period (Table 1); solid samples such as a gasket need no preparation.</td></tr>
<tr><td>Reagents to be used</td><td>Dräger or Sensidyne tubes: Acklands-Grainger, Unit 106, 1220 Old Innes Road, Ottawa ON K1B 3V3 (price is about CAN$80/box of 10 tubes; diffusion tubes are also produced by other companies).</td></tr>
<tr><td>Comments</td><td>
<p>The coated enclosure or test chamber holding the samples must remain closed for 2 days prior to the test. Insert the diffusion tube, with one end open, into the enclosure for a specific period. The introduction of the tube into the enclosure must generate as little air exchange as possible; inserting the tube through a drill hole is one option and covering the opening of the enclosure with a plastic bag while inserting the tube is another.</p>
<p>The diffusion tube will change colour to indicate the presence of pollutants. The limits of detection (LD) are expressed in ppm x h; the lower LD is calculated by dividing the ppm by the maximum exposure in hours.</p>
<table>
<tr><th>Dräger Tubes</th><th>LD (ppm x h)◊</th><th>Interference by:</th><td rowspan="17">Figure 6. Diffusion tube (a) and tube for short-term measurement (b).


(a) (b)</td></tr>
<tr><td>acetic acid</td><td>10</td><td>acid volatile compounds, SO_2</td></tr>
<tr><td>ammonia</td><td>20</td><td>alkaline particles</td></tr>
<tr><td>ethyl acetate</td><td>500</td><td>2-butanone, alcohol, ethyl glycol acetate</td></tr>
<tr><td>hydrochloric acid</td><td>10</td><td>SO_2, NO_2, Cl_2</td></tr>
<tr><td>hydrogen sulfide</td><td>10</td><td>Cl_2, NO_2, NH_3, H_2S</td></tr>
<tr><td>nitrogen dioxide</td><td>10</td><td>—</td></tr>
<tr><td>sulphur dioxide</td><td>5</td><td>HCl, NO_2, Cl_2, acetic acid</td></tr>
<tr><td>toluene</td><td>100</td><td>ethyl benzene, xylene</td></tr>
<tr><td>tolylene diisocyanate (TDI)</td><td>0.02 ppm □</td><td>—</td></tr>
<tr><td>Sensidyne Tubes</td><td></td><td></td></tr>
<tr><td>ammonia</td><td>25</td><td>alkaline particles</td></tr>
<tr><td>formaldehyde</td><td>1</td><td>aldehydes, ketones, carboxylic acids</td></tr>
<tr><td>hydrogen sulphur</td><td>10</td><td>Cl_2, NO_2, NH_3, SO_2</td></tr>
<tr><td>nitrogen dioxide</td><td>1</td><td>Cl_2</td></tr>
<tr><td>sulphur dioxide</td><td>5</td><td>NO_2, H_2S</td></tr>
<tr><td>toluene</td><td>10</td><td>probably same as for Dräger tubes</td></tr>
</table>
<p>The date of coating application and the date of analysis must be specified. Details of the test chamber parameters should be provided if results are to be used for comparison.</p>
<p>◊: see Appendix 2 for unit conversion of ppm in mg/m^3.
□: TDI is measured with short-term measurement Dräger tubes.</p>
</td></tr>
<tr><td>Acceptable test results</td><td>
<p>Diffusion tubes cannot detect inorganic gases at the low levels usually recommended for museums. No widely accepted standards exist for allowable levels of organic volatile compounds. See Appendix 2 for control levels and/or background levels of those compounds.</p>
<p>Alternative tests: Dräger tubes for short-term measurements for room or large-volume enclosures [84], and Tests 4 and 7.</p>
</td></tr>
</table>

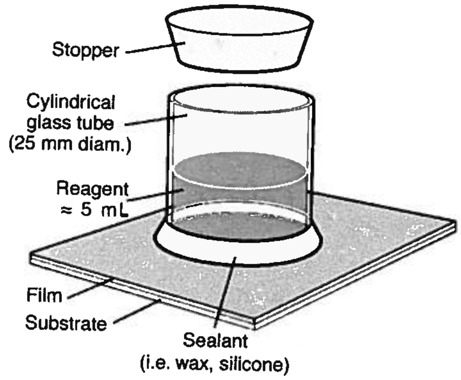
Test 7	**Chromatographic Techniques**
Purpose of test	To determine the specific volatile compounds released by a sample. Appendix 1 provides information on the harmful effect of various volatile compounds.
Test methodology	The adsorption method is used before the chromatographic analysis to accumulate small amounts of volatile compounds. Various approaches exist such as: Grzywacz, C.M., and N.H. Tennent. "Pollution Monitoring in Storage and Display Cabinets: Carbonyl Pollutant Levels in Relation to Artefact Deterioration" [85]; Martin, G., and N. Blades. "Cultural Property Environmental Monitoring" [86]; Gibson, L.T., et al. "A Diffusion Tube Sampler for the Determination of Acetic Acid and Formic Vapors in Museum Cabinets" [87]; Tétreault, J., and E. Stamatopoulou. "Determination of Concentrations of Acetic Acids emitted from Wood Coatings in Enclosures" [1].
Sample preparation	In a test chamber, liquid samples should be dried on aluminum foil for the recommended period (Table 1); solid samples such as a gasket need no preparation.
Comments	The coated enclosure or the test chamber holding the samples must remain closed for 2 days prior to the test. Insert the absorbent/reactant material into the enclosure for a specific period. The introduction of the absorbent material into the enclosure must generate as little air exchange as possible; introduction of the absorbent/reactant materials through a drill hole is one option and covering the opening of the enclosure with a plastic bag while inserting the materials is another. Analysis of the trapped volatile compounds must be done by an analytical laboratory; limits of detection will vary according to the technique used and the type of volatile compounds. The date of coating application, the date of analysis, and details of the experimental setup must be specified. Details of the test chamber parameters must be provided if the results are to be used for comparison. Figure 7. Examples of absorbent/reactant materials to trap volatile compounds; GMD badge [85] (a), Palmes diffusion tube [87] (b), and Carbotrap 300 [1] (c).  (a) (b) (c)
Acceptable test results	No widely accepted standards exist for allowable levels of organic volatile compounds. See Appendix 2 for control levels and/or background levels of those compounds. Alternative tests: Tests 4 and 6. Medium and high cost electronic monitors based on electrochemical and optical methods are also available. For more information on these monitors consult safety material suppliers.

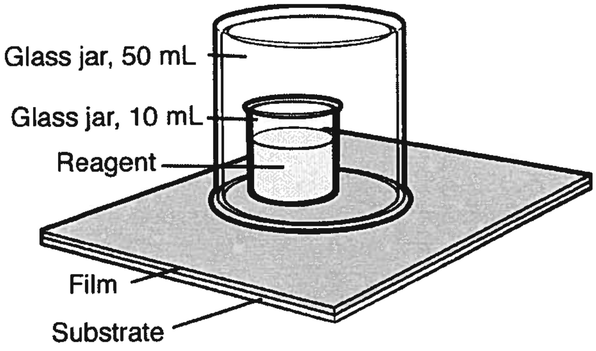
Test 8	**Accelerated Corrosion Test**
Purpose of test	To evaluate the harmful effects of volatile compounds on metal objects; referred to as the Oddy test.
Test methodology	Green, L.R., and D. Thickett. "Testing Materials for Use in the Storage and Display of Antiquities—A Revised Methodology" [88].
Sample preparation	Liquid samples should be dried on aluminum foil for the recommended period (Table 1); solid samples such as a gasket need no preparation.
Reagents to be used	Common test coupons are lead, silver, and copper; other coupons such as lead white pigment can also be used.
Comments	Metal coupons should be enclosed in a jar with a film or material sample at high RH and 60°C for 28 days. Lead coupons react mainly with carboxylic acids and aldehyde compounds; silver and copper coupons react mainly with sulphur compounds. Triplicate samples must be done for each test coupon. The date of coating application and the date of testing must be specified. Figure 8. Schematic representation of the accelerated corrosion test. 
Acceptable test results	For a film or material to be acceptable, the metal coupon must not be altered during the aging process. Of 21 film samples tested by the British Museum, 30% were unsuitable for copper, 50% were unsuitable for lead, and 16% were unsuitable for silver [89]. Alternative test: A (non-accelerated) corrosion test; place metal coupons in the newly coated enclosure for 3 months and compare results with a control outside the enclosure.

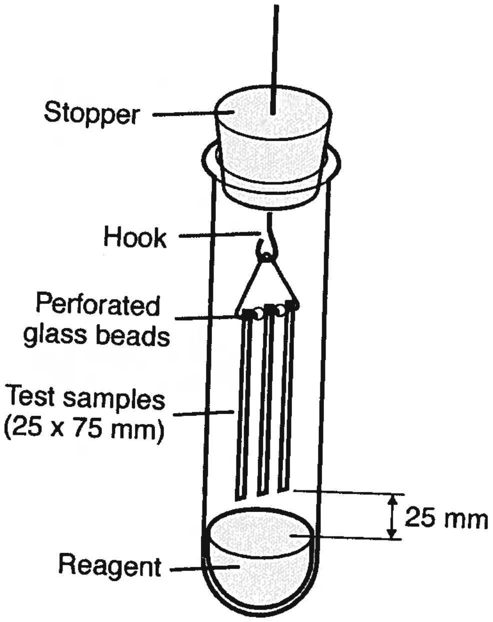
<table>
<tr><th>Test 9</th><th colspan="2">Photographic Activity Test</th></tr>
<tr><td>Purpose of test</td><td colspan="2">To evaluate the effect of a test sample on a photographic image.</td></tr>
<tr><td>Test methodology</td><td colspan="2">ANSI/NAPM 1T9.16-1993. “Photographic Activity Test - American National Standard for Imaging Media” [90].</td></tr>
<tr><td>Sample preparation</td><td colspan="2">Twice-coated samples should be dried on aluminum foil (at least 110 x 20 mm) for the recommended period (Table 1); solid samples such as a gasket need no preparation.</td></tr>
<tr><td>Reagents to be used</td><td colspan="2">Colloidal silver detector: Image Permanence Institute, Rochester Institute of Technology, Frank E. Gannett Memorial Building, Rochester NY 14623-0887, USA.
Stain detector: non-resin-coated black-and-white photographic paper processed without development.</td></tr>
<tr><td>Comments</td><td>An oven at constant 70°C and 86% RH for 15 days is required for this test. The density changes of the detectors should be measured with a densitometer.
The date of coating application and the date of testing must be specified.
Films formed by oxidative polymerization give strong positive results [91].</td><td>Figure 9. Schematic representation of the photographic activity test (two test samples are run at the same time).

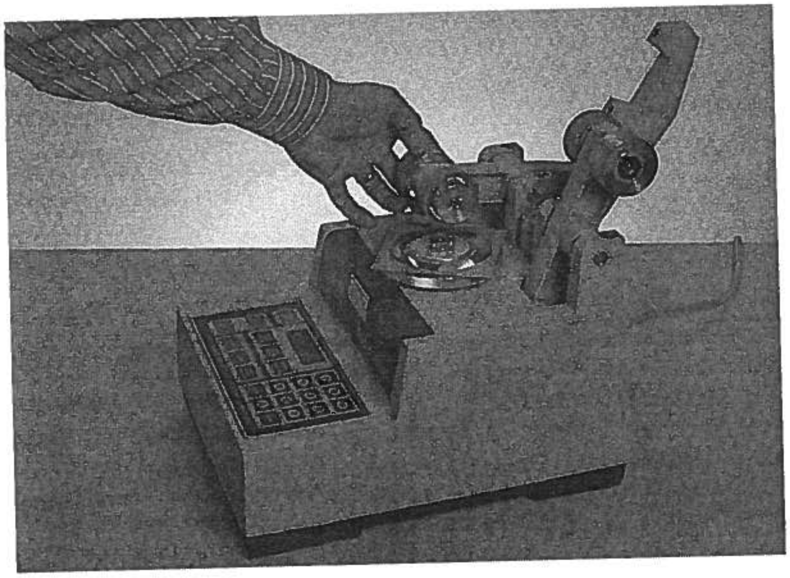


</td></tr>
<tr><td>Acceptable test results</td><td colspan="2">For a film or material to be acceptable, the maximum ΔDAg permitted with colloidal silver detector is 20% and the maximum ΔDgel permitted with stain detector is 0.08.
Alternative test: Contact test (sandwich test) to evaluate the interaction between the test sample and a material. Prepare stacks as shown in Figure 9 and heat them in an oven at constant 60°C and 100% RH for 28 days as described in Test 8. For the test sample to be approved for use, no visual change should be observed compared with a control.</td></tr>
</table>

Test 10	**Chemical Resistance of Film to Liquids**
Purpose of test	To determine the chemical resistance of films to liquids; to determine how well protected a coated substrate is against chemical spoiling.
Test methodology	ASTM. "D 3363-92a. Standard Test Method for Film Hardness by Pencil Test" [93].
Sample preparation	Baked coatings should be at least 1 day old and unbaked coatings should be dried for the recommended period (Table 1); the dimension of all samples should be at least 3 x 5 cm.
Reagents to be used	The list of reagents should be chosen according to the nature of the artifact and the presence or eventual use of chemicals in the enclosure. 1. No reagent. 2. Water (23°C). 3. Ammonia (3.5% v/v). 4. Ethyl alcohol in water (95%). 5. Methyl ethyl ketone (MEK). 6. Formaldehyde solution in water (40%). 7. Acetone. 8. Chlorinated cleaning solution (e.g. Lysol disinfectant). 9. Mineral spirit. 10. Boric acid solution (9.5%). 11. Propylene glycol. 12. Fatty acids from mammals and birds. 13. Essential oils from aromatic plant specimens. 14. Insecticide in spray form (water- or oil-based) containing pyrethrins. 15. Insecticide in emulsion form containing diazinon (trade names Basudin, Neocidol, or Spectracide). Figure 10. Schematic representation of the film in contact with reagent.  16. Insecticide in emulsion (Emulsifiable Concentrate: EC), micro-encapsulated (Basudin), or oil-based form containing bendiocarb wettable powder (WP) (trade names Ficam or Dexaklor). 17. Insecticide in emulsion, spray, or oil-based form containing propoxur (trade names Baygon or Blattanex). 18. Insecticide in spray form containing resmethrin (trade name Synthrin). 19. Disinfectant incorporating quaternary ammonium salts (e.g. Actiphene Germicidal Cleaner, Anti-Staph, products containing BTC-2125 or Hyamine 3500). 20. Insecticide in emulsion, water solutions, paints containing chlorpyrifos (trade name Dursban). 21. Insecticide in EC form containing permethrin (trade names Dragnet or Prelude). 22. Insecticide in WP form containing cypermethrin (trade name Demon 40 WP).
Comments	The coated samples should be immersed in a sealed glass jar full of the reagent; if it is not possible to fill the jar the reagent must be in contact with the coated sample as shown in Figure 10. A sealant or a gasket will be required to avoid spilling. Test and record the hardness of the coated metal samples in accordance with Method D 3363 after 2 min of contact with the reagent and after 24 h of exposure to room environment following 24 h of contact with the reagent. Start with the hardest lead and hold it firmly against the film at a 45° angle. Push away for a stroke length of at least 7 mm. This test is very subjective and therefore not very reliable. The date of coating application and the date of testing must be specified.
Acceptable test results	For a film to be acceptable, it must not be cut or scratched by a 4H or softer pencil when tested with no reagent; by an H or softer pencil after 2 min of contact with the reagent; and by a 4H or softer pencil after 24 h of contact and 24 h of recovery.

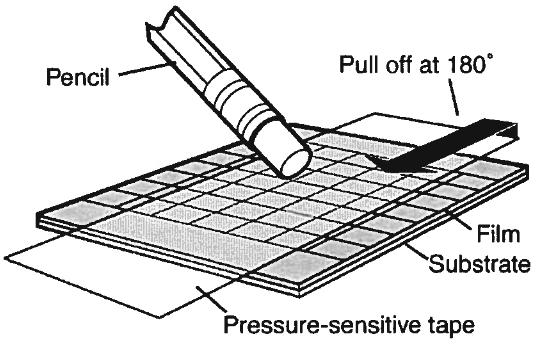
Test 11	**Chemical Resistance of Film to Vapours**
Purpose of test	To determine the chemical resistance of films to vapours; to determine how well protected a coated substrate is against chemicals in vapour phase.
Test methodology	ASTM. “D 3363-92a. Standard Test Method for Film Hardness by Pencil Test” [93].
Sample preparation	Baked coatings should be at least 1 day old and unbaked coatings should be dried for the recommended period (Table 1).
Reagents to be used	The list of reagents should be chosen according to the nature of the artifact and the presence or eventual use of chemicals in the enclosure. 1. No reagent. 2. Water vapour (75% RH). 3. Ammonia (3.5% v/v). 4. Ethyl alcohol in water (95%). 5. Methyl ethyl ketone (MEK). 6. Formaldehyde solution in water (40%). 7. Acetone. 8. Chlorinated cleaning solution (e.g. Lysol disinfectant). 9. Mineral spirit. 10. Acetic acid (1*M*). 11. Nitric acid (1*M*). 12. Hypochlorite bleach. 13. Paradichlorobenzene (PDB). 14. Sulphuric acid (6*M*). 15. Naphthalene. 16. Dichlorvos (2,2 - dichlorovinyl dimethyl phosphate) (“DDVP”) in resin (Vapona strips), emulsion oil-based form. Figure 11. Schematic representation of the film in the presence of vapour. 
Comments	Fill a small glass bottle with reagent and place it upright on the finished surface of the sample. Invert a glass over the reagent bottle so that the rim is in contact with the sample as shown in Figure 11. Remove the sample after 24 h and let it aerate for another 24 h, then test and record the hardness of the finished surface exposed to the vapours in accordance with Method D3363. Start with the hardest lead and hold it firmly against the film at a 45° angle. Push away for a stroke length of at least 7 mm. This test is very subjective and therefore not very reliable. The date of coating application and the date of testing must be specified.
Acceptable test results	For a film to be acceptable, it must not be cut or scratched by a 4H or softer pencil when tested with no reagent or when tested after 24 h of vapour exposure and 24 h of recovery.

Test 12	**Chemical Resistance of Plastic to Vapours**
Purpose of test	To determine the chemical resistance of plastic to chemicals in vapour phase; if the coated parts of an enclosure are tested (e.g. Test 11), plastics such as gaskets included in that enclosure should also be tested.
Test methodology	Modification of: ASTM. "D 543-95. Standard Test Method for Resistance of Plastics to Chemical Reagents" [94].
Reagents to be used	The list of reagents should be chosen according to the nature of the artifact and the presence or eventual use of chemicals in the enclosure. 1. No reagent. 2. Water vapour (75% RH). 3. Ammonia (3.5% v/v). 4. Ethyl alcohol in water (95%). 5. Methyl ethyl ketone (MEK). 6. Formaldehyde solution in water (40%). 7. Acetone. 8. Chlorinated cleaning solution (e.g. Lysol disinfectant). 9. Mineral spirit. 10. Acetic acid (1*M*). 11. Nitric acid (1*M*). 12. Hypochlorite bleach. 13. Paradichlorobenzene (PDB). 14. Sulphuric acid (6*M*). 15. Naphthalene. 16. Dichlorvos (2,2 - dichlorovinyl dimethyl phosphate) ("DDVP") in resin (Vapona strips), emulsion oil-based form. Figure 12. Schematic representation of test samples suspended in the test tube. 
Comments	Section 10.2 of Method D 543 should be changed so that the samples are suspended 25 mm above the 10 mL of reagent as shown in Figure 12. The samples should be suspended for 7 days or subjected to conditions agreed upon by the supplier and the client. The date of coating application and the date of testing must be specified.
Acceptable test results	For a material to be acceptable, there should be no visible changes in the sample (no loss of elastomeric qualities such as tensile or compressive strength, and no tackiness, softening, and brittleness).

Test 13	**Resistance of Film to Abrasion**
Purpose of test	To determine the abrasion resistance of film.
Test methodology	ASTM. "D 4060-90. Standard Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser" [95].
Sample preparation	Baked coatings should be at least 1 day old and unbaked coatings should be dried for the recommended period (Table 1).
Comments	Test samples should be mounted on the abraser's rotating turntable and subjected to the wearing action of two abrasive wheels applied at a specific pressure as shown in Figure 13. The procedure should be carried out in accordance with Method D 4060 as follows: abrasive wheel: CS - 17 Taber wheel and 1000 cycles. Figure 13. Taber Abraser.  The date of coating application and the date of testing must be specified.
Acceptable test results	For a film to be acceptable, the weight loss must not exceed 100 mg for drawers or public and heavy traffic floors.

Test 14	**Differentiation between Emulsion and Alkyd Films**
Purpose of test	To differentiate between emulsion and alkyd; a primer will be required for proper adhesion if a drying oil-based film is to be coated with an emulsion coating.
Reagents to be used	Denatured alcohol.
Comments	Wet a rag with denatured alcohol and rub the surface of the film.
Results	If the film softens or rubs off it is most likely a latex. An alcohol test will usually not affect a drying oil-based film.

Test 15	**Moisture Content**
Purpose of test	To determine the moisture content of wooden and cementitious substrates with a moisture meter; if the curing process is not complete or the moisture content is higher than recommended, adhesion will not be optimal and the film may fail prematurely.
Comments	Press the moisture meter firmly against the substrate. No substrate preparation is required. Pin-free moisture meters are preferable; pin-type moisture meters can be used but they will leave pin holes.
Acceptable test results	The moisture content should be less than 15% for wood substrates, masonry, or plaster. Alternative test: Check for moisture on bare concrete floors by taping a 5 x 5 cm piece of 0.1-mm (4 mil) plastic to the floor with duct tape and leaving it overnight. Remove it next day and look for signs of moisture on the underside of the plastic or darkening of the concrete (ASTM Test Method D 4263 [96]).

<table>
<tr><th>Test 16</th><th colspan="2">Film Adhesion</th></tr>
<tr><td>Purpose of test</td><td colspan="2">To determine whether or not the adhesion of a film to a substrate is adequate.</td></tr>
<tr><td>Test methodology</td><td colspan="2">ASTM. “D 3359. Standard Test Method for Measuring Adhesion by Tape Test”; Cross-Cut Tape Test (Method B) [97].</td></tr>
<tr><td>Sample preparation</td><td colspan="2">Baked coatings should be at least 1 day old and unbaked coatings should be dried for a minimum of 7 days; the dimensions of all samples should be at least 3 x 5 cm.</td></tr>
<tr><td>Comments</td><td>Make a lattice pattern with six (20-mm-long) cuts in each direction on the coated substrate as shown in Figure 14. Apply a 25-mm-wide pressure-sensitive tape with an adhesion strength agreed upon by the contractor and the client over the lattice (3M tapes #610 and #250 are often used; their adhesion strengths are 48 and 73 g/mm (43 and 65 oz./in.), respectively). To ensure good contact with the film, rub the tape firmly with the blunt end of a pencil. Remove the tape after 1 or 2 min by seizing the free end and rapidly pulling it off at an angle as close to 180° as possible. The adhesion is evaluated by comparison with a reference scale ranging from 5B (no flaking) to 0B (flaking and detachment at more than 65% of the lattice).
Keep in mind that there will always be variation in the adhesion strength of the tape along the roll, from roll to roll, and from lot to lot.
The date of coating application, the date of testing, and the tape used must be specified.</td><td>Figure 14. Schematic representation of the cross-cut tape test.
 </td></tr>
<tr><td>Acceptable test results</td><td colspan="2">To be acceptable, the film must meet classification 5B (no flaking or loss from the lattice). Indicate where any flaking occurs: between first coat and the substrate, between first and second coat, etc.
Alternative test: Patch test for compatibility. Apply the coating on a clear previously coated surface (60 x 60 cm). Examine the patch area immediately and 24 h after coating, looking for softening, lifting, blistering, bleeding, or streaky discoloration.</td></tr>
</table>

Appendix 4. Coating selection worksheet and coating specifications

Table 3. Coating selection worksheet.

Project name **Location**				
Substrate	Wood species:	Metal:	Cementitious subst., specify:	Other, specify:
Object(s)	Type:		Sensitivity to volatile compounds (Appendix 1):	
Airtightness of the enclosure	Airtight	Leaky	Open (ventilated encl. or room)	Other, specify (such as floor):
Period of use	< 1 year	1–10 years	>10 years	
Function of the film	Aesthetic (colour, gloss), specify:			
	Protect objects from volatile compounds released by the substrate (Tests 4–8), specify compounds of concern:			
	Protect objects from contact with compounds in the substrate (Test 9 or contact test included in Test 9), specify compounds of concern:			
	Protect substrate from compounds released by the objects, fumigants, or any other chemical treatments (Tests 10–12), specify compounds of concern:			
	Protect substrate from abrasion (Test 13): Provide hard film surface (Test 10):			
Film emissivity and transfer of compounds	Presence or absence of volatile compounds released by the coating that are harmful to objects (Tests 4–8), specify compounds of concern:			
	Presence or absence of compounds that can be transferred from the coating to the objects by contact (Tests 1–3 and 9, including contact test), specify compounds of concern:			
Resin(s) and film(s)-forming mechanism proposed with respective drying period (Table 1)				
Budget for the project				
Budget for testing			% of project budget:	
Special requirements				

Table 4. Coating performance specifications.

Specifications (specify coatings/materials if necessary)	Tests available	Tests required	Acceptable results	Results obtained	Tests run by
Absence of sulphur in test sample	1. Lead acetate test		No sulphur detected		
Absence of formaldehyde in test sample	2. Chromotropic acid test		No formaldehyde detected		
Absence of chloride in test sample	3. Beilstein test		No chloride detected		
Absence and level of acid volatile compounds released by test sample/enclosure	4. Glycerol/pH test		No difference in pH between the test sample/enclosure and the blank		
Low acidity of the wood	5. pH measurement		pH > 5		
Absence of various volatile compounds released by test sample/enclosure	6. Diffusion tubes		No more than CL, BL, or level specified for each volatile compound◊, specify:		
	7. Chromatographic techniques				
Absence of corrosive volatile compounds released by test sample	8. Accelerated corrosion test with silver, copper, lead coupons or other Ag		No corrosive volatile compounds		
	Cu				
	Pb				
Absence of compounds reactive to photographic test sample with contact	9. Photographic activity test with colloidal silver and stain detectors		Coll. silver: $\Delta D_{Ag} < 20\%$		
			Stain: $\Delta D_{gel} < 0.08$		
Absence of compounds reactive to test sample with contact	9. Contact test		No change		
Hard film	10. Pencil test		>4H		
Chemical resistance of test film to different liquids	10. Pencil test		>2H after 2 min >4H after 24 h + 24 h		
Chemical resistance of test film to different vapours	11. Vapour exposure test		>4H		
Chemical resistance of plastic such as gasket to different vapours	12. Incubation test		No change		
Resistance of film to abrasion	13. Taber Abraser		Weight loss ≤100 mg		
Specifications for the quality of the coating application					
Film adhesion	14. Identification of previous coating and patch test		Must be compatible		
	15. Moisture content		Moisture content ≤15%		
	16. Tape test		No detachment (5B)		
Dry film thickness	Coating thickness gage		≥0.13 mm (≥5 mil)		
Comments on test results					
◊ For control levels and background levels see Appendix 2.					