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Pesticide Contamination: Working Together to Find a Common Solution. The Current State of Affairs

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Pesticide Contamination: Working Together to Find a Common Solution

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Abstract

The need to detect a broader range of pesticides and to develop more quantitative analyses has grown as the repatriation of Aboriginal objects has become more frequent and commonplace. This paper summarizes information from literature surveys and object testing that shows the extent and type of pesticide contamination on museum objects. Global objectives for assessing pesticide-contaminated cultural objects are outlined. The most recent developments in X-ray fluorescence spectrometry (a common methodology for detecting inorganic pesticide residues) and the detection of organic pesticide residues such as naphthalene, para-dichlorobenzene, and DDT amongst others are presented. Future steps include developing collaborations that can lead to providing meaningful toxicological assessments of the artifacts to the users along with handling guidelines or recommendations. Mitigation is currently being studied, but not by these authors, and remains an area for future research.

Titre et Résumé

La contamination par les pesticides : la concertation en vue d'une solution commune
À mesure que le rapatriement d'objets autochtones devient plus courant, le besoin de dépister une plus vaste gamme de pesticides et d'élaborer des analyses plus quantitatives augmente. Dans cet article, on présente un sommaire des informations recueillies lors de recherches documentaires et d'évaluations d'objets, expliquant le genre et l'ampleur de contamination des objets de musée par des pesticides. On décrit les objectifs généraux touchant l'évaluation de résidus de pesticides dans des objets culturels et, en plus, on explique les progrès récents dans le domaine de la spectrométrie à fluorescence X (une méthode répandue pour dépister des résidus de pesticides inorganiques) et le dépistage de résidus de pesticides organiques, notamment le naphthalène, le 1,4-dichlorobenzène et le dichlorodiphényltrichloroéthane (DDT). Les prochaines étapes comprennent l'établissement de collaborations en vue de fournir aux usagers des évaluations toxicologiques visant en particulier les objets qui les concernent et, en outre, des lignes directrices ou des recommandations touchant la manipulation. L'atténuation fait actuellement l'objet d'études par d'autres chercheurs, et demeure un domaine de recherche à approfondir.

Introduction

Over the last 20 years, the issue of pesticide residues on cultural objects has received much attention — in particular with the repatriation of Native materials. Repatriation may create situations where the objects are used in very different ways than they would be in their museum setting. For example, the objects may move from a controlled environment where the potential hazards are likely known by those handling them, to one where the objects are used by a public unaware of the possible presence of pesticide residues. This paper provides an overview of pesticide contamination on cultural objects, identifies work being carried out by many individuals and institutions, and notes common areas of interest for future research and discussion.

NAGPRA, Repatriation, and the Evolution of Artifact Use

One factor that has raised awareness of pesticide contamination, while at the same time creating a more urgent need to find ways to identify and quantify the extent of contamination, is the practice of repatriation. Through a formal legal process in the United States, and various more informal methods in other countries, items that have been housed in museums for decades are being returned to their communities of origin. In the United States, this return process is legislated for most museums under the *Native American Graves Protection and Repatriation Act* (NAGPRA), which became law in 1990. Section 10.10(e) of the 1996 NAGPRA Final

Regulations specifically requires museums and federal agencies to disclose "any presently known treatment of human remains, funerary objects, sacred objects or objects of cultural patrimony with pesticides, preservatives or other substances that present a potential health hazard to the objects or the persons handling the objects." After the objects are returned, they may be used in ways that were never considered when they were in museums. Many of these uses entail increased handling and contact — objects may be worn and carried in ceremonies, stored in private homes, refurbished, and repaired. All of these activities provide more opportunities for pesticides that may still contaminate the objects to transfer to the individual using the item (Johnson and Pepper Henry 2002; Loma'omvaya 2001; Sadongei 2001; Haakanson 2004).

In addition to repatriating objects, museums may lend items from their collections to Indigenous communities for use in ceremonies and exhibits (Clavir 2002; Johnson, Heald, McHugh et al. 2005). This leads to situations where many community members have access to the objects and could be exposed to pesticide contamination. This includes both Elders and children, who may be more easily affected by the contaminants (Reigart 1999; Florida Department of Health 2007). Objects are also routinely handled during traditional museum practices such as conservation treatment, mount-making, and research. Finally, the expansion of consultations on how to care for and exhibit objects in museums is leading to more possibilities for community members to be affected by contaminants as they now have the opportunity to handle the material more frequently.

The Potential History of an Object — Reported Pesticide Use in Museums

While this review identifies the wide range of pesticides that was used on museum objects in the United States and Canada, it does not identify what was used on any individual item. When considering a specific item or collection, it is important to review the records of the institution in which it is housed. An historical review can also limit the amount of testing necessary to identify contamination on a specific object.

The list of materials used in the preparation of taxidermy specimens is long and varied (Williams and Hawks 1987). One of the more traditional "preservatives" employed was arsenical soap, invented by French pharmacist Jean-Baptiste Bécoeur (1718–1777). The recipe was published in 1800 (Péquignot 2006), and arsenical soaps and compounds have since been frequently recommended for use in the field of natural history. Published sources suggest that similar techniques were used on both natural history specimens and ethnographic objects made of organic material (Goldberg 1996; Hawks 2001). A number of anthropology and natural history curators published preparation or "housekeeping" methods aimed at educating others in the preservation of their collections (Hornaday 1905; Hough 1889). More recently, some museums have published information on possible pesticides applied to their collections. This knowledge benefits individuals who handle the collections (Austin et al. 2005; Nason 2001; Odegaard and Sadongei 2005; Goldberg 1996). A comprehensive list of toxic chemicals potentially present in museums can be found in the literature (Goldberg 1996; Hawks 2001; Rossol and Jessup 1996; Williams and Hawks 1987; Odegaard and Sadongei 2005; Pereira and Hammond 2001; Pool 2004).

Documentary evidence of pesticide use in American institutions

In the past, museums typically kept incomplete records of pesticide treatments. The Smithsonian Institution has done archival research to determine possible pesticides used in the National Museum of Natural History (NMNH) (Goldberg 1996). Some pesticides identified in that review, with associated dates if available, were:

- tobacco, camphor, sulphur, arsenic, and corrosive sublimate (mercuric chloride) (1830s–1860s)
- strychnine in arsenical solutions (reported in 1887)
- naphthalene, thymol, and salicylic acid (1889)
- more volatile poisons such as carbon disulphide prevalent post 1913 with the advent of closed storage cabinets; later on para-dichlorobenzene used interchangeably with naphthalene (post 1931) and ethylene dichloride – carbon tetrachloride (1940)
- hydrocyanic acid gas was mentioned as a fumigant for rugs (1931)
- Larvex (sodium aluminum fluorosilicate) (1930s)
- DDT (dichloro-diphenyl-trichloroethane) (1946)
- liquid fumigants were used inside storage cabinets — a carbon tetrachloride, ethylene dichloride, and ethylene dibromide mixture [Dowfume G] (1961–1967), Dowfume 75 (ethylene dichloride and carbon tetrachloride) and dimethyl formamide (1965)
- methyl bromide fumigation (~1957–1971)
- Dichlorvos (or DDVP, 2,2-dichlorovinyl dimethyl phosphate), ethylene oxide, and Vikane (sulphuryl fluoride) (post-1969)

In a 1982 survey of museums in New York City, 27 museums were found to use assorted pesticides and fumigants. The most commonly reported pesticides were (listed here in order of decreasing use): ethylene oxide, para-dichlorobenzene, pyrethrins, thymol, naphthalene, methoxychlor, ethyl alcohol, Dursban (chlorpyrifos — an organophosphate), methyl bromide, formaldehyde, chlordane, and Ficam W (bendiocard — a carbamate) (Rossol and Jessup 1996). Other pesticides listed as being in common use in a "Center for Occupational Hazards Data Sheet" were Dowfume 75, Dichlorvos, Vikane, and carbon disulphide (Rossol and Jessup 1996).

Documentary evidence of pesticide use in Canadian institutions

Canadian museum publications from the first half of the 20th century also included information on various pesticides used. A 1929 Annual Report of the National Museums of Canada, at that time consisting of the National Gallery of Canada, the National Museum of Man, and the National Museum of Natural Science[1] (National Museums Task Force 1986), suggested "a wholly satisfactory fumigant was evolved"; it was a mixture of three parts ethylene dichloride with one part of carbon tetrachloride (Leechman 1929). The use of carbon disulphide, hydrocyanic acid gas, and chloropicrin was also mentioned as well as naphthalene and para-dichlorobenzene (Leechman 1931). Sodium fluoride was used to control cockroaches along baseboards and radiator pipes and a solution of mercuric chloride in alcohol was suggested as an effective fungicide (Leechman 1931).

A National Museums of Canada Bulletin dating from 1948 suggested the following pesticides for use in natural history collections: naphthalene, para-dichlorobenzene, arsenic–borax mixtures, arsenic–alum mixtures, arsenical soaps, DDT, sulphur, carbon disulphide, and a mixture of ethylene dichloride and carbon tetrachloride (Anderson 1948). White arsenic diluted in water or sodium arsenite diluted with water applied to skins to prevent infestation was also suggested (Anderson 1948).

Literature collected by the Canadian Museum of Civilization (CMC) showed that it had received advice on pest control methods from other museums through a request for assistance made to the National Research Council of Canada (Béland 1964). The National Research Council then consulted other museums and passed the information back to CMC. Recommendations included carbon disulphide, naphthalene, and para-dichlorobenzene; the treatment of specimens mounted for exhibition by the application of various solutions of arsenic compounds (Anderson 1964); and Dowfume, Paracide crystals, and arsenical soaps for mothproofing (Hobbs 1964). CMC also frequently consulted Agriculture Canada in the 1960s and 1970s for information on pesticides and how to deal with pests (Creelman 1969) both through correspondence and through published pamphlets which they collected. Some pesticides mentioned in these publications were chlordane, DDT, diazinon, malathion, lindane, pyrethrum powder, and sodium fluorosilicate (Andison 1960; Creelman 1969; MacNay 1967a, 1967b).

A 1965 publication by Agriculture Canada on the control of fabric pests stated that suitable commercial pest control formulations "may contain 2–5% DDT, 0.5% dieldrin, 2% chlordane or various silicofluorides" (MacNay 1965). Around 1974, commercially available mothproofing sprays for household use contained combinations such as methoxychlor with pyrethrum and piperonyl butoxide; resmethrin with tetramethrin; and pyrethrum with piperonyl butoxide (Agriculture Canada 1974). In 1965, Agriculture Canada recommended an application of commercially available household products (dusts) that contained 10% DDT, 5% chlordane, or 2% dieldrin prior to laying rugs. The 1974 version of the same publication recommended using dusts with 5% chlordane or 1% lindane. Household sprays may have contained 3% malathion (premium grade), 2% chlordane, 0.5–1% propoxur, or 0.5–1% diazinon (Agriculture Canada 1974). As these publications show, formulations change over time.

Pesticide Analysis

Though archival research of a museum's pesticide history may shed light on what pesticides were used at the institution, the complete pesticide history of individual objects is rarely known. In the absence of written records, objects must be analysed directly for the presence of pesticide residues.

The typical aim of analysis is to determine what pesticides are present along with how much is present and how it is distributed across the object. A variety of detection techniques have been developed and/or adapted for this purpose. Each is suited for the identification of certain pesticides, but no single technique can identify them all. Consequently, pesticides are categorized into groups based on the methods used for their detection. The most common distinction is "inorganic" versus "organic" pesticides. Inorganic pesticides are compounds that are, in general, mineral derivatives and are not based on carbon. These compounds tend to contain a heavy metal element such as arsenic, mercury, or lead, or a lighter, non-metallic element such as boron. Most inorganic pesticides can be identified by

X-ray fluorescence spectrometry (XRF), which generally detects the presence of elements above atomic number 13 (aluminum) in the periodic table, but does not identify the exact compound. "Organic" pesticides are compounds that are based on the element carbon. These generally cannot be identified by XRF because they do not contain distinctive elements detectable by this technique (i.e. those above atomic number 13). Gas chromatography – mass spectrometry (GC–MS) is the technique usually employed to analyse museum objects for organic pesticides. It is these two techniques, XRF and GC–MS, that the Canadian Conservation Institute (CCI), the National Museum of the American Indian (NMAI), and the Museum Conservation Institute (MCI) have been working to improve so that more quantitative data can be provided for both inorganic and organic pesticide detection.

The form a pesticide takes, i.e. solid, liquid, or vapour, determines how the sample will be collected and analysed. Chromatographic techniques require that a sample be removed from the object, as a solid, liquid, or gas/vapour. Volatile pesticides can emanate from an object as a vapour or gas. For this reason, these compounds can potentially be detected in the air around an object. Most volatile pesticides are organic although mercury-containing compounds are also known to be volatile. Non-volatile pesticides remain on an object as a solid or liquid and do not diffuse into the surrounding air.

The various techniques for pesticide analysis differ not only in the pesticides that can be identified, but also in the minimum amount of pesticide that can be detected (known as the lower limit of detection), the cost, and the sampling or testing method. XRF and GC–MS are only two of the many techniques used to detect pesticides. One other technique often used to detect pesticide residues in the museum community is spot tests. Spot tests — which are more economical and can be used when access to the more expensive instrumentation is not available — can be used to detect some organic and inorganic pesticides (Odegaard et al. 2000). Spot test kits are available to determine the presence of arsenic, organophosphate compounds (e.g. dichlorvos, chloropyrifos, and malathion), carbamate compounds (e.g. carbofurn and carbaryl), and borate pesticide residues such as boric acid (Odegaard and Sadongei 2005).

The goals of analysis are to be able to detect the least amount of pesticide that would be expected to cause an adverse health effect, and to carry out the analysis with minimal or no damage to the object.

Confirmation of the Use of Pesticides Through Analyses

Many pesticides reported to have been used in museums have been confirmed through analysis. During the last 20 years, chemical spot tests (Hawks and Williams 1986; Odegaard et al. 2000; Henry 1996; Found and Helwig 1995) and XRF have been the two most commonly used techniques to detect certain chemical elements associated with pesticide residues. These include arsenic, lead, mercury, and bromine. XRF became more popular once hand-held units were financially viable for museums, around the year 2000. Arsenic, mercury, lead, and bromine have frequently been detected in museum artifacts, predominantly in natural history and anthropology collections (Muir et al. 1981; Sirois and Taylor 1988; Sirois 2001; Sirois and Sansoucy 2001; Found and Helwig 1995; Morrow 1993; Odegaard and Sadongei 2005; Johnson, Heald, and Chang 2005; Nason 2001; Palmer et al. 2006).

Other organic chemicals detected through analysis of museum artifacts studied to date include:

- para-dichlorobenzene (Glastrup 1987; Palmer et al. 2006; Ormsby et al. 2006)
- naphthalene (Glastrup 1987; Palmer et al. 2006; Ormsby et al. 2006)
- DDT (Glastrup 1987; Palmer et al. 2006; Vingelsgaard and Schmidt 1986; Poulin 2004; NIOSH 1983)
- methoxychlor (Glastrup 1987; Poulin 2004; Vingelsgaard and Schmidt 1986)
- lindane (Palmer et al. 2006; Sirois 2001; Vingelsgaard and Schmidt 1986)
- perthane (Poulin 2004)
- bromine — most likely from methyl bromide fumigation (bromine may also be present from other sources such as fire retardants) (Mack 2004)
- thymol (Palmer et al. 2006)
- limonene (Ormsby et al. 2006)
- nicotine — which was detected on objects stored with tobacco leaves (Poulin 2004)

Global Objectives to Further Develop Pesticide-contaminated Artifact Assessment

The many complex and overlapping issues facing contaminated collections ultimately promotes new collaborations among individuals from many backgrounds to develop appropriate responses. These individuals may include object caretakers such as cultural centre staff, community members who care for the object, curators, conservators, scientists, toxicologists, and others. Since 2000, when a conference was sponsored by the Arizona

State Museum at the University of Arizona, a number of meetings between different stakeholders in various parts of North America have been held. The focus of these meetings was to raise awareness of the issue, share information, and work towards developing a coordinated approach to the diverse issues involved in identifying pesticides, accessing and using objects safely, and (more recently) mitigating the problem through removal techniques. Formal symposia and conference sessions that resulted in publications are listed in Table 1. Smaller, more informal meetings have also been sponsored by museums and tribes to broaden the knowledge about the issues of contaminated collections. Participants at these meetings are developing strategies that are leading to better collaborative sampling and testing approaches between museums and tribes and more quantitative analytical methods. Work is also leading towards methods to identify, interpret, and report the hazards of using contaminated objects in ceremonial and other non-museum contexts.

During discussions at these meetings, several prominent areas that require further development were identified:

- Testing must be done through a collaborative process that ensures all stakeholders understand the needs and issues of the process.
- Standards and methodologies of techniques currently in use, in particular portable XRF technologies, need to be improved to give more quantitative data.
- Methods for the identification of organic pesticides must be further developed to give more quantitative data.
- Analytical data need to be presented in a way that leads to the ability to make informed decisions on safe use, particularly for objects that will be put back into use through repatriation and loans.
- Levels of pesticide contamination need to be correlated with health risk.
- Simple, usable, mitigation methodologies must be developed.

Work is now ongoing in all these areas.

New Developments in the Analysis of Pesticide Residues

XRF calibration standards for inorganic pesticides

Hand-held XRF is used to identify elements characteristic of inorganic pesticide residues present on Aboriginal objects and, ideally, to give an idea of the concentration. The technique is non-invasive, does not require sampling, and can identify the elements in question within minutes (Nason 2001). Pesticides that contain arsenic, mercury, lead, bromine, and other elements with an atomic number higher than 20 (calcium) in the periodic table can be detected in parts per million concentrations on many artifact substrates. Elements below this (elements between silicon and potassium) are generally detected in the percentage range.

The current goal of XRF research is to improve the accuracy of concentration data for inorganic pesticides so that health and safety professionals, including medical toxicologists and assessors of exposure and risk, can make more accurate assessments of health risk. To do this, the XRF instrument must be calibrated to well-characterized references of known composition that are representative of cultural materials. The creation of such reference materials was first suggested in a meeting of professionals who use XRF in pesticide detection that was held at the Arizona State Museum in 2004 (see Table 1) (Thomson 2004). Since then, several groups have prepared artifact-appropriate reference materials to calibrate their hand-held XRF spectrometers for arsenic, mercury, and lead (Bond 2007; Madden and Shugar 2007; Anderson 2006; Hahne and Nason 2001).

In 2005, the Arizona State Museum prepared calibration curves for arsenic, mercury, and lead by doping feathers, cotton textile, and wool textile with known quantities of these elements (Anderson 2006). Also in 2005, the Smithsonian Institution's MCI, in consultation with NMAI, NMNH, CCI, the National Institute for Standards and Technology (NIST), and the U.S. Environmental Protection Agency (EPA), initiated fabrication of standards for arsenic that can be distributed to groups that use hand-held XRF for pesticide detection on artifacts. In 2007, arsenic calibration standards that are specific for organic museum objects were prepared by MCI in conjunction with NIST (Madden and Shugar 2007). The standards are pellets of arsenic trioxide in a matrix of microcrystalline cellulose. Some standard reference materials that have been developed by NIST for use in other industries may be appropriate in the museum context and are available for purchase. Of these, the lead paint standards (SRM 2579a) can be used in analysis of paint films and other surface layers that contain concentrations of lead in the range of 0.3–4 mg/cm^2 (http://www.nist.gov/srm). Multi-element standards in a plastic matrix, such as polyethylene or polyvinyl chloride, have recently been developed to help electronics manufacturers comply with governmental directives concerning the safe use and disposal of elements such as lead, mercury, bromine, chromium, and cadmium. Such standards are commercially available and are fairly

Table 1. Meetings held on pesticides and artifact repatriation, with a list of ensuing publications

Date	Conference/Workshop/Symposium	Location	Publication
March 2000	Contaminated Cultural Material in Museum Collections	Arizona State Museum, Tucson, Arizona	Odegaard, N., and A. Sadongei. "Contaminated Cultural Materials in Museum Collections; Reflections and Recommendations for an NAGPRA Issue." *WAAC Newsletter* 22, 2 (2000), pp. 18–20
August 2000	Repatriation of Sacred Indian Artifacts Treated with Pesticides and Other Chemical Preservatives: Health Risks to Users and to Conservators	International Society of Environmental Epidemiologists Conference, Buffalo, New York	
September 2000	The Contamination of Museum Materials and the Repatriation Process for Native California	San Francisco State University	*Collection Forum* 16, 1–2 (Winter 2001)
April 2001	Contaminated Collections in Museums: Preservation, Access and Use	National Conservation Training Center, Shepherdstown, West Virginia	*Collection Forum* 17, 1–2 (Fall 2001)
May 2002	17th Annual Meeting of the Society for the Preservation of Natural History Collections. Conference Theme: Hazardous Collections and Mitigations	Redpath Museum, Montreal, Quebec	http://www.spnhc.org/2002/program.htm
January 2004	XRF Workshop	Arizona State Museum, Tucson, Arizona	
May 2004	Aboriginal Repatriation Conference	Masset, Haida Gwaii, British Columbia, Canada	http://aboriginalrepatriation.org/speakers_abstracts.html
November 2004	Contaminated Collections and Inherent Collection Hazards	Eastern Analytical Symposium, Somerset, New Jersey	*Collection Forum* 20, 1–2 (Spring 2006)
October 2006	XRF Pesticide Workshop	Arizona State Museum, Tucson, Arizona	
April 2007	Mitigation of Pesticides on Museum Collections	Smithsonian MCI, Suitland, Maryland	*Mitigation of Pesticides on Museum Collections. Proceedings of Seminar held at the Smithsonian Institution MCI April 23–24, 2007* (edited by A.E. Charola). Forthcoming
September 2007	Preserving Aboriginal Heritage: Technical and Traditional Approaches (including the post-symposium workshop *Pesticide-contaminated Collections* and the Technical Meeting *XRF for Pesticide-contaminated Collections*)	Canadian Conservation Institute, Ottawa, Ontario, Canada	*Preserving Aboriginal Heritage: Technical and Traditional Approaches* (2008)
November 2007	Cultural Heritage Between Conservation and Contamination — The Issue of Biocidal Products in Museum Collections and Monuments	Rathgen Research Laboratory, National Museums, Berlin, Germany	Forthcoming

representative of organic museum artifacts (http://www.armi.com).

Research and development of artifact-specific calibration standards is an ongoing need. Single-element standards for mercury, as well as thin-film standards for arsenic and pellet-style standards for lead, have not yet been developed. More multi-element standards are also needed to model inter-element interferences that can skew XRF data. Finally, standards are needed that replicate matrices other than cellulose or plastic. XRF data can vary among different artifact materials such as bone, animal hide, wood, and feathers due to differences in density, thickness, and the combination of elements present (Madden and Shugar 2007).

Analysis of organic pesticides using GC–MS

Renewed interest in detecting organic pesticides has arisen due to repatriation of museum objects. This has led to the need to develop more quantitative methods for small museum samples and pursue the detection of a wider range of organic pesticides.

Recently, there has been an increased use of GC–MS, which is ideally suited to the identification and quantification of trace levels of organic pesticides. This technique is used commonly by EPA and the agricultural industry to detect organic pesticides, and it has been adapted to museum objects at institutions including CCI and the Smithsonian Institution. One main advantage lies in the simplicity of sample preparation prior to analysis on the GC–MS.

As with all analytical techniques, sampling is a vital part of the analysis. Non-volatile organic pesticide residues have been sampled by CCI by wiping a precleaned cotton swab on the object or by collecting a powdery sample onto a glass-fibre filter with a micro-vacuum pump. Volatile pesticides such as naphthalene and para-dichlorobenzene have been analysed successfully with GC–MS using a solid phase microextraction (SPME) sampling apparatus (Ormsby et al. 2006) and passive air diffusion cartridges (Sirois and Sansoucy 2001). Passive diffusion air monitors are used to sample the air in the storeroom or near an object on a shelf.

After the samples are removed from the objects they must be prepared for analysis. For samples of particulate matter, removed from the artifact via swabbing or micro-vacuuming, the samples are removed from the sampling substrate with an appropriate solvent. Acetone has proven to be suitable for a range of organic pesticides including:

- organophosphates (e.g. dichlorvos, diazinon, and malathion)
- organochlorines (e.g. DDT, DDD, DDE, methoxychlor, and dichlorobenzene)
- carbamates (fenobucarb and terbucarb) (Schmidt 2001; Murayama et al. 2000)

For samples of volatile components such as dichlorvos and naphthalene that have been collected using passive diffusion air cartridges, the charcoal membranes from the cartridges should be extracted in an appropriate organic solvent prior to analysis by GC–MS.

Mitigation

Researchers have started to investigate methods of pesticide mitigation. Techniques that have been investigated — some only in a preliminary manner — include HEPA-filtered vacuuming, compressed air, laser, exposure to ultraviolet light, washing, freeze drying, and chemical alteration (Odegaard 2001; Odegaard and Zimmt, pp. 217–225 in these *Proceedings*). Several current mitigation research projects were presented at the symposium hosted by the Smithsonian Institution's MCI in April 2007 (Charola forthcoming). One approach currently being investigated is pesticide residue removal using super critical fluid extraction with carbon dioxide (Tello et al. 2005; Zimmt et al. forthcoming), or liquid carbon dioxide (Tello and Unger forthcoming). Microbial detoxification of mercury contamination is also being investigated (Roane 2004; Roane forthcoming), as is the use of surface-active displacement solutions (SADS) involving a longer chain aliphatic alcohol such as butanol, a surfactant, and water (Reuben 2006; Hill and Reuben, pp. 195–199 in these *Proceedings*; Reuben forthcoming). The use of aqueous alpha-lipoic acid solutions to remove arsenic (III) and mercury salts from materials is also currently being studied (Cross forthcoming). Other promising methods exist and further investigation is needed to assess these potential methods of decontamination.

Future Steps

Though much of the recent work on contaminated collections has focussed on methods and techniques for identification, this is only one part of the process. These methods must be fine-tuned to deliver more accurate quantitative results. Once contamination has been identified, there needs to be a way to provide meaningful toxicological assessments of the artifacts for the users and to provide handling guidelines directly related to the intended use. Ideally, medical toxicologists and industrial hygienists should be part of the team identifying and interpreting the contamination of objects (Odegaard et al. 2006). The testing methods being developed will also serve to assist with determining when an artifact can be considered "usable" once research into mitigation is further developed.

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Endnote

1. The National Gallery of Canada was founded in 1880, the National Museum of Man (now the Canadian Museum of Civilization) and the National Museum of Natural Science were both founded in 1912 and evolved from the museum of the Geological Survey of Canada founded in 1842 (National Museums Task Force 1986).

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