Pesticide Residues on the Cook-Voyage Collections at the Pitt Rivers Museum, University of Oxford

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Abstract

Eighteen objects from the Cook-voyage collections at the Pitt Rivers Museum, University of Oxford (PRM), were analysed for selected pesticide residues, using gas chromatography-mass spectrometry (GC-MS) and inductively coupled plasma-mass spectrometry (ICP-MS), followed by analysis with a hand-held X-ray fluorescence unit (HH-XRF). The intention was to discover what pesticides had been used on the collections to better inform conservation decision-making. The results showed that the collection had been treated with a range of organic and inorganic pesticides. The analytical methods applied proved to be complementary, with XRF used as an initial qualitative screen for the detection of elements found in inorganic pesticides, and ICP-MS and GC-MS providing data for elements in inorganic and targeted organic pesticides respectively. The results of the analytical methods could not be directly compared due to the large number of variables present in the methodology.

Keywords

Ethnographic, Cook-voyage, pesticide, hand-held XRF, GC-MS, ICP-MS

Introduction

The Cook-voyage collections at the Pitt Rivers Museum, University of Oxford (PRM) date from the first and second voyages (1768-1771, 1772-1775). Joseph Banks, the naturalist on the first voyage, gave a collection to Christ Church, his Oxford college, in 1772. The naturalists Johann Reinhold and George Forster, father and son, gave the second voyage collection to Oxford University in 1776. This collection was originally housed in the Ashmolean Museum. Both collections were transferred to the newly opened Pitt Rivers, the University Museum of Anthropology and Archaeology, in 1886.

Pesticides were used on museum collections to treat active pest infestation, and to prevent future attacks. William Bullock's 'A Concise and Easy Method of Preserving Subjects of Natural History', (1817), gives a recipe for preserving powder, used on specimens at Bullock's Museum, which included objects collected by Banks on Cook's first voyage. The powder contained arsenic, and could be turned into a soap for application to skins. Pests were mentioned in the PRM annual reports (Table 1) but the chemical methods used to mitigate insect attack were never specified. We can however conclude that the Cook-voyage collections have been treated with pesticides over the years, and residues of these chemicals are likely to remain on the surface.

Reporting Year	Quote
1903	'As I pointed out in my last report, the funds formerly expended in paying an assistant have had to be assigned to the purchase and erection of exhibition cases, cabinets, &c., for the protection of valuable specimens and series of specimens from the ruin caused by dust, the attacks of beetles and moths, and other causes, as well as by frequent handling by visitors.'
1906	'The addition of a fuming-room, in which specimens infected with moth and beetle may be cured, will be of great convenience, and will greatly lessen the trouble caused by insect depredations'
1946-47	'…we have tried the Clymax spray (made by Clymax Supplies Ltd., of 67 Essington Street, Birmingham 15) on all of our material, and have found it thoroughly effective in destroying every sort of pest that attacks every sort of material that human beings use'
1950	'…the whole of the Technical Staff have been engaged throughout the year in going through all the collections to guard them against moth, woodworm, and all the pests that attack most of the objects used by human beings.'
1955	'…he has made about a third of our textiles mothproof.'
1956	'…we are noting how many things he did that were necessary and useful for museum work and for our teaching programme, working the lantern for lectures…treating many specimens against moth and other destructive agents…'
1959	'We could work with confidence that we should find our very varied specimens in good condition, since throughout the year as usual Mr. H.F. Walters was superintending the regular inspection and treatment of the collections to save them from the innumerable pests that prey on the various materials of which they are made.'
1963	'…going through all the collections to ensure their health against moth, woodworm, and all other insect pests'

Table 1. Pests in the Pitt Rivers Museum, University of Oxford Annual Reports

Even before 1886 there had been problems with pests - a label attached to the Tahitian Mourner's costume, written by curators at the Ashmolean before the transfer of objects to the PRM, reveals that 'The cloak worn by the figure was had away from the Ashmolean previously to fumigate it.' This was carried out in the Oxford University Museum of Natural History (OUMNH). It is probable that techniques used for the preservation of Oxford University's natural history collections would have been used on ethnographic collections from the Ashmolean. Practices for pest control at OUMNH include the application of borax and white arsenic, and the treatment of active pest infestations with petrol and turpentine (Nowak Kemp, pers. comm. 2013). The Pitt Rivers possibly used a methyl bromide fumigation chamber during the early 1980s.

The analysis of pesticide residues on objects in the Cook-voyage collections was carried out as part of a conservation project to conserve the Cook-voyage collections at the PRM, funded by the Clothworkers' Foundation. Pesticide residues on collections have become an issue, particularly since the publication of works such as 'Old Poisons, New Problems' (Odegaard 2005) and the work done by Jane Sirois. (Sirois et al 2007, 2012). Spot tests for arsenic were carried out in the Conservation Laboratory, and display cases monitored with a portable mercury vapour indicator. We wanted to know more about which pesticides were present on the collections and what the implications might be, for staff, research visitors, and members of originating communities who wished to handle objects without gloves. We need to make more informed decisions about handling protocols under these circumstances. It was assumed that the Cook-voyage collections have been exposed to a range of pesticides available to museums during the last 250 years.

Initially, sampling protocols were developed to test for pesticide residues. The work was carried out with the Food and Environment Research Agency (Fera), part of the UK Government Department for the Environment, Food and Rural Affairs (Defra).

Cook-voyage objects were selected for testing based on several factors. Barkcloths and mats were chosen because of a large surface area for testing. Stained and dirty areas were targeted during sampling (Figure 1).

Figure 1. Staining on surface of barkcloth, Mus. No. 1886.1.1240

Feather headdresses and a feather cloak were chosen because feathers are frequently attractive to insect pests, and they are likely to have been targeted with pesticides in the past (Figure 2).

Figure 2. A feather headdress, Marquesas, Mus. No. 1886.1.1340

The Tahitian Priest’s helmet had been restored in 1970, and by taking samples from restored and unrestored areas we hoped to understand how pesticides have been used more recently (Figure 3).

Figure 3. The *fau*, showing the 1970 restoration

The majority of the sampled Cook-voyage objects were subsequently analysed using an HH-XRF. These are becoming common in museums, often bought specifically to test objects for inorganic pesticide residues. It was intended to see if a comparison was possible between the results obtained using the HH-XRF and those obtained by GC-MS and ICP-MS.

GC-MS and ICP-MS Methodology

Sampling

The need for non-destructive sampling imposed limitations on methodology. The only solvent considered safe to use with the objects was distilled water. A procedure using cotton wool moistened with water was investigated for its suitability for pesticide residue sampling. Water is a poor solvent for many of the pesticides likely to be present, due to their low solubility. However, the cleaning process mechanically removed tiny amounts of surface dirt, which transfer surface pesticide residues without dissolution. Approximately 100 swabs from different areas of an object were combined to maximise likelihood of detection of residues and to try to get a representative measurement for the whole object. Swabs prepared at the same time but not exposed to museum objects were used as controls. All swabs were stored in polypropylene plastic tubes in a freezer (- 20 °C) until analysis to prevent microbial decomposition.

Organic pesticides analysis

Swabs (about half of total sample; 30 - 45 swabs) were counted and accurately weighed then extracted with ethyl acetate. Agitation with a glass rod and an ultrasonic bath were used to aid dissolution of residues. The ethyl acetate and swabs were partitioned with saturated sodium chloride in water. The ethyl acetate layer was separated and residual water removed by shaking with anhydrous magnesium sulphate. The extract was filtered and analysed by GC-MS.

Feather sub-samples from loose feathers found in storage boxes (approximately 100 mg, accurately weighed) were shaken with ethyl acetate (2 mL) and agitated using an ultrasonic bath. The ethyl acetate solution was analysed directly by GC-MS.

Instrumentation: GC-MS

An Agilent Technologies 6809 gas chromatograph (GC) with an Agilent 5973 Mass Selective Detector (single quadrupole mass spectrometer (MS)) was used for the analysis. A DB-5MS GC column (30 m x 0.25 mm i.d. with 0.25 µm film thickness (Agilent Technologies) was used with helium carrier gas for the chromatographic separation. The GC was operated in splitless injection mode (250 °C) with temperature-programmed oven (isothermal at 50 °C for 1 minute, then 5 °C/min to 80 °C, 10 °C/min to 250 °C and 20 °C/min to 300 °C, isothermal for 10 minutes). The MS was operated in selected ion monitoring mode to acquire mass-spectral data for 21 analytes (Table 2).

Calibration solutions were prepared from solutions of certified pesticide reference materials diluted with extracts from control swabs (Sigma-Aldrich Company Ltd., UK and QMx Ltd., UK).

Analyte	**Chemical Type**
Aldrin	Organochlorine pesticide
Chlordane	Organochlorine pesticide
Chlorpyrifos	Organophoshate pesticide
Chlorpyrifos-methyl	Organophosphate pesticide
Dichlorodiphenyltrichloroethane (p,'p-DDT)	Organochloride pesticide
Dichlorvos	Organophosphate pesticide
Dieldrin	Organochlorine pesticide
Endosulfan	Organochlorine pesticide
Endrin	Organochlorine pesticide – closely releated to aldrin
Gamma-hexachlorohexane (γ-HCH)	Organochlorine pesticide - Lindane
Heptachlor	Organochlorine pesticide
Hexachlorobenzene (HCB)	Organochlorine pesticide
Napthalene	Aromatic hydrocarbon, used as a pesticide in the form of mothballs
Para-dichlorobenzene (p-DCB)	Aromatic hydrocarbon, replacement for naphthalene as a pesticide in mothballs
Permethrin	Synthetic pyrethroid pesticide
Thymol	Monoterpene phenol used as pesticide
Dichlorodiphenyldichloroethylene (p,'p-DDE)	Breakdown or transition product of p,'p-DDT
Dichlorodiphenyldichloroethane (p,'p-DDD)	Breakdown or transition product of p,'p-DDT
Heptachlor expoxide	Breakdown or transition product of heptachlor
Oxychlordane	Breakdown or transition product of chlordane
Endosulfan sulfate	Breakdown or transition product of endosulfan

Table 2. Analytes selected for detection with GC-MS

Inorganic pesticides analysis

Swabs (about half of total sample; 30 - 45 swabs) were counted and accurately weighed. The swabs were ultrasonicated and shaken in sufficient 1% nitric and 0.5% hydrochloric acid in water to give a concentration of two swabs per mL. The extracts were diluted ten-fold with 1% nitric and 0.5% hydrochloric acid in water and analysed directly by ICP-MS.

Feathers (approximately 100 mg, accurately weighed) were treated in the same way as the swab samples, but extract volume was 10 mL. The extracts were diluted ten-fold before analysis.

Instrumentation: ICP-MS

An Agilent Technologies 7700x ICP-MS system fitted with a collision cell operated in either 'no gas' or 'helium' mode (depending on the analyte) was used to determine arsenic and mercury as well as 67 other metallic elements, using Agilent default settings. External calibration was performed against certified National Institute of Science and Technology reference solutions.

Performance of the sample preparation methodology for organic pesticide analysis was checked by spiking control swabs with pesticides (approximately 2.5 ng per swab) before analysis. The inorganic pesticide sample preparation used established methodology that did not require further performance checks for this application.

Experimental Results and Discussion

Despite water being a particularly poor solvent for DDT and DDE, residues of these and a variety of others were frequently detected on the 18 objects sampled (Tables 3 and 4).

		residue (ng per swab; feathers ng per mg)							
sample number	**sample description**	**p-DCB**	**naphthalene**	**thymol**	**γHCH**	**p,'p-DDE**	**dieldrin**	**p,'p-DDD**	**p,'p-DDT**
1886.1.1124	maori rain cape	<0.05	**7.1**	**0.61**	<0.2	**0.078**	<1	<0.5	<1
1886.1.1137	maori cloak	<0.05	**2.1**	**8.2**	<0.2	**0.035**	**3.1**	<0.5	<1
1886.1.1171	mat, Tahiti	<0.05	**3.3**	**13**	<0.2	**0.095**	**9.8**	<0.5	<1
1886.1.1175	mat, Tonga*	<0.05	**1.6**	<0.5	<0.2	<0.03	<1	<0.5	<1
1886.1.1240	barkcloth, Tahiti	<0.05	**2.6**	<0.5	<0.2	<0.03	<1	<0.5	<1
1886.1.1248	barkcloth, Tahiti	<0.05	**2.9**	**0.56**	<0.2	<0.03	<1	<0.5	<1
1886.1.1257	mat, Tahiti	<0.05	**3.1**	**7.8**	<0.2	**0.067**	**7.2**	<0.5	<1
1886.1.1340	headdress, Marquesas	<0.05	**6.3**	**4.3**	<0.2	**0.070**	**2.1**	<0.5	<1
1886.1.1528	headdress, Easter Island*	<0.05	**0.90**	<0.5	<0.2	<0.03	<1	<0.5	<1
1886.1.1637	mourner's costume cloak (reverse of mask)*	<0.05	**5.5**	**3.8**	<0.2	**0.23**	<1	<0.5	<1
1886.1.1637	mourner's costume cloak	<0.05	**8.4**	**0.56**	<0.2	**0.064**	**1.2**	<0.5	**1.0**
1886.1.1637	mourner's costume cloak feathers*	<0.01	**3.9**	<0.5	<0.04	**0.04**	<1	<0.5	**2.3**
1886.1.1637	mourner's costume cloak feathers	<0.01	**95**	**3.2**	<0.04	**0.11**	**3.5**	<0.5	**2.2**
1886.1.1683	fau, Tahiti	<0.05	**42**	**2.0**	<0.2	**0.13**	**4.8**	<0.5	**8.2**
1886.1.1683	fau, Tahiti (1970s restoration)	<0.05	**5.8**	**0.80**	<0.2	**0.080**	**3.4**	<0.5	**9.9**
1886.21.16	barkcloth	<0.05	**4.7**	<0.5	<0.2	**0.11**	<1	<0.5	<1
1886.21.17	barkcloth, Tahiti	**0.12**	**11**	<0.5	**0.53**	**0.19**	<1	<0.5	<1
1886.21.18	barkcloth	<0.05	**5.3**	<0.5	<0.2	<0.03	<1	<0.5	<1
1886.21.19	maori cloak	<0.05	**3.0**	**2.1**	<0.2	**0.21**	<1	<0.5	**5.3**
1886.21.29	barkcloth	**0.092**	**9.7**	**0.69**	<0.2	**0.12**	<1	<0.5	<1
	control	<0.05	**0.75**	<0.5	<0.2	<0.03	<1	<0.5	<1

Table 3. Results from organic pesticide analysis of swabs and feathers (GC-MS)

		residue (ng per swab, feathers ng per mg)		
sample number	**sample description**	**As**	**Hg**	**Pb****
1886.1.1124	maori rain cape	**6.3**	**2.5**	**170**
1886.1.1137	maori cloak	**1.8**	<1	**110**
1886.1.1171	mat, Tahiti	**9.4**	**4.1**	**4000**
1886.1.1175	mat, Tonga*	**22**	**3.9**	**5300**
1886.1.1240	barkcloth, Tahiti	**2.7**	<1	**530**
1886.1.1248	barkcloth, Tahiti	**12**	**5.3**	**180**
1886.1.1257	mat, Tahiti	**6.1**	<1	**1200**
1886.1.1340	headdress, Marquesas	**8.5**	**27**	**450**
1886.1.1528	headdress, Easter Island*	**6.5**	**3.0**	**190**
1886.1.1637	mourner's costume cloak (reverse of mask)*	**63***	**3.4**	**6800**
1886.1.1637	mourner's costume cloak	**7.8**	**2.4**	**140**
1886.1.1637	mourner's costume cloak feathers*	**4.6**	<1	**91**
1886.1.1637	mourner's costume cloak feathers	**6.9**	**2.6**	**100**
1886.1.1683	fau, Tahiti	**13**	**2.0**	**580**
1886.1.1683	fau, Tahiti (1970s restoration)	**3.5**	**2.0**	**170**
1886.21.16	barkcloth	**9.3**	**430**	**2100**
1886.21.17	barkcloth, Tahiti	**38**	**670**	**3200**
1886.21.18	barkcloth	**5.0**	**6.3**	**140**
1886.21.19	maori cloak	**18**	**230**	**280**
1886.21.29	barkcloth	**15**	**190**	**1300**
1945.11.130	mat, Tahiti	**14**	**470**	**690**
-	control	<1	<1	<5

Table 4. Results from inorganic pesticide analysis of swabs and feathers (HH-XRF)

These findings support the idea that they are transferred in the trace amounts of solid material removed by the swabs. Recovery of the organic pesticides from spiked swabs was quantitative, ranging from 96% (RSD 1.6%) for p,p'-DDE to 76% (RSD 7%) for p,p'-DDT, although the actual proportion of residues recovered by swabs from objects for any of the pesticides detected or undetected, cannot be ascertained in the absence of ‘control objects’. Consequently, the measurements for residues on swabs cannot be extrapolated to residue concentrations on objects. With the exception of dieldrin, the feather samples analysed gave similar results to those from the swabs from the mourner’s costume. The distribution of residues over the surface of these objects is unknown, since swabs were pooled to improve limits of detection, but they are likely to vary according to location and construction material, as the results for the feathers and swabs from different areas of the mourner’s costume show.

Arsenic, mercury and naphthalene residues were the most frequent and largest pesticide residues identified on swabs. Elevated lead levels were found in several samples. These were orders of magnitude larger than the arsenic residues, which suggest that they are probably from a source other than lead arsenate – one possible arsenic pesticide compound. Since lead is a fairly ubiquitous contaminant, these residues might be present due to environmental contamination, such as from vehicle emissions. Levels of boron were detected in Mourner’s costume swabs and feathers that were elevated above general background levels for other swabs. Boron occurs naturally in many soils and plant materials, which might explain its presence, but it could also be due to boric acid used as an insecticide and fungicide.

HH-XRF Methodology

Non-destructive HH-XRF analysis was undertaken on 14 objects, already sampled for testing with GC-MS and ICP-MS. Object analyses were performed in the Conservation Department with the exception of large objects, which were analysed in the museum stores (Figure 4).

Figure 4. Kelly Domoney taking HH-XRF readings from the *fau.* Mus. No. 1886.1.1683

An Oxford Instruments X-MET 5100 X-ray fluorescence analyser with a silicon drift detector, rhodium tube and 8mm beam diameter was used for all analyses. As the analytical parameters are pre-set by the manufacturer, voltage setting in the parameters within the Soil-FP mode (45kV, 15µA and 25µm iron filter) was deemed high enough to excite heavy elements of interest - lead, mercury, arsenic and bromine. Oxford Instruments ‘Soil standard 3a2’ and a graphite blank were run at the beginning and end of each session in order to check the calibration and measure the background. In most instances, three 60-second measurements were taken from different locations on the outer flattest surface of each object to check if the pesticide was homogenously applied. Due to the nature of many of the objects under analysis (i.e. mats, barkcloth, feathers), an Oxford Instruments ‘non-fluorescing background plate’ was placed beneath the objects, to prevent excitation of elements within the support materials. The variability of the materials and associated absorption properties under analysis meant that results would be qualitative or semi-quantitative at best, i.e. an indication of the relative concentrations between objects. Elements present within each spectrum were identified using Bruker Artax software (Version 7.0.0.) and their associated peak intensity counts were calculated in order to assess relative concentrations.

Experimental Results and Discussion

Results of the HH-XRF analyses are discussed here in relation to material type.

Barkcloth - Mercury and bromine are observed throughout the surface of three of the five barkcloths (1888.1.1256, 1886.21.17 and 1886.21.29). As shown in Figure 5 the highest levels of those elements are observed in areas with dark stains, as well as high levels of iron (1888.1.1256 and 1886.21.17). Lead occurs on all objects at low levels (<800 counts) with the exception of the mid-coloured stain on object 1888.1.1240, where elevated lead is observed (~ 1900 counts).

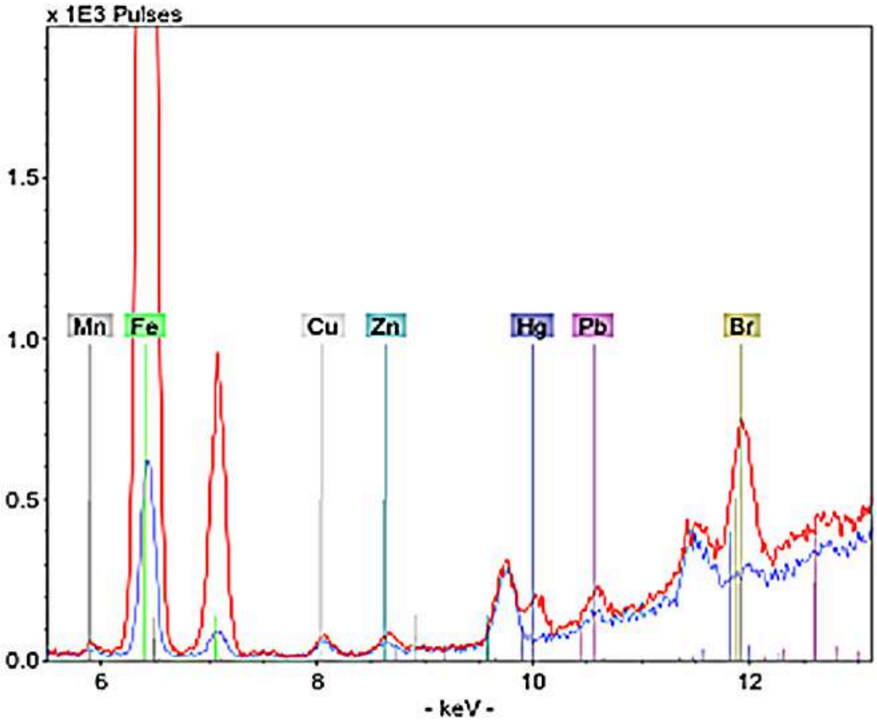

Figure 5. HH-XRF spectra of dark stained (red) and non-stained (blue) areas of bark cloth 1888.1.1256

Feathers - All feathers have similar levels of calcium, titanium, potassium, copper, iron and strontium with the exception of 1886.1248, in which strontium is below detection levels. Two objects (1886.1.1340 and 1888.1.1528) exhibit high iron. Lead is observed at mid to high levels (1000-60000 counts) on all feathered objects, with the highest levels (~60000 counts) observed on 1886.1.1683. Bromine and mercury occur together on three objects, and mercury is present without bromine on 1886.1.1340.

Dog hair - A Maori cloak with dog hair tassels (Figure 6) exhibits the highest levels of mercury and bromine of all the objects tested. The dog hair tassels have three to four times the level of mercury and twice the level of bromine than the cloth substrate. High levels of iron are observed in the cloth substrate, at similar levels to the dark stains observed on bark cloth 1888.1.1256.

Figure 6. Maori cloak with dog hair awe 1886.21.19

Mats - Of the three Tahitian mats analysed in this study, two have bromine (with or without trace mercury) and one has mercury without bromine. The mat from Tonga (1888.1.1175) has bromine with possible traces of mercury.

In summary, low levels of lead occur on all objects, with feathered objects consistently exhibiting the highest levels. Of the 14 objects analysed, mercury and bromine occur in conjunction on 11, mercury (without bromine) occurs on two, and two objects (bark cloths) do not exhibit mercury or bromine. Elevated levels of zinc occur on three objects (one mat and two feathered objects). It was difficult to identify the presence of arsenic in any of the objects due to the peak overlap of arsenic Kα with lead Lα and arsenic Kβ with mercury Lβ and bromine Kα. Calcium, titanium, potassium, copper, iron and/or strontium occur on all materials, and may be attributed to the substrate material, or contamination. (Shugar and Sirois 2012).

Conclusions

Using the methodology described it was possible to show that the Cook-voyage collections held in the PRM were treated with a range of pesticides. The residues detected represent a spread of pesticide types, from arsenic and mercury, certainly in use by 1817, to the modern organochlorine compounds such as lindane. Lindane was only withdrawn from use in 2006, though in the museum its use was discontinued at least 20 years before that.

Not all the pesticides detected are on all the objects sampled, although the use of naphthalene and thymol appears to have been widespread. They were probably used as residual pesticides in storage areas,.

Featherwork appears to have been targeted with pesticides, particularly with DDT and dieldrin. This was expected, as museum documentation suggests that some of the feathered objects in the Cook-voyage collections have been badly affected by insect pests in the past.

It is likely that barkcloths and mats were sprayed or treated while folded, accounting for the dark stains present on some of them in certain areas. These stains, some having the appearance of water damage, were always a subject of speculation amongst museum conservators, and the results of both types of analysis show that stained areas are associated with higher levels of pesticide residues. Many of the barkcloths exhibit surface damage to fibres only in these areas, suggesting that application of pesticides to the surface may be accelerating degradation. The main author has seen Cook-voyage barkcloths in other collections known to have been treated with DDT in the 1960s, which show similar degradation, though more advanced.

Comparison of the GC-MS/ICP-MS analysis carried out on the original feathers from the *fau*, and the feathers added in 1970, would suggest that naphthalene and thymol were still in use after 1970 Dieldrin and DDT levels are fairly consistent between the two areas, which implies that these pesticides were in use in the 1970s. Likewise, mercury levels in the two areas were found to be the same, suggesting that mercuric compounds were still being applied to objects until fairly recent times, and that the results are not because of cross contamination.

One surprising result of the analysis has been the levels of lead present on the surface of all of the objects. Environmental contamination has been mentioned as a possible source. It is also possible that in the past petrol was sprayed on objects to treat active pest infestations, or used as a solvent for pesticides.

For practical purposes, the HH-XRF can detect inorganic pesticide residues, based on lead, arsenic, mercury and bromine (in the form of bromide, a harmless residue associated with the use of methyl bromide). It is more difficult to obtain the full spectrum of pesticide residues on an object, particularly with regard to trace levels of lighter elements (e.g. chlorine in the case of mercuric chloride). As previously discussed, peak overlaps limit the potential for the detection of arsenic on objects that have been treated with mercury and lead-based pesticides, which could be seen to limit the potential for using the HH-XRF on ethnographic material heavily contaminated with a range of inorganic pesticide residues. However, results indicate that the technique could be used as a qualitative screen for detecting the presence of elements typically found in inorganic pesticides, prior to selecting quantitative instrumentation (depending on sampling methods). For example, the XRF readily detected bromine, an element not selected for measurement in the previous ICP-MS analysis.

Comparison of analytical methods is difficult. There appears to be broad agreement (apart from detection of arsenic) in terms of whether an element is present or not, for example, where results for mercury levels were less than 1ng/swab for ICP-MS analysis, they were below the detection level for the HH-XRF (barkcloth 1886.1.1240, mat 1886.1.1257). A larger sample size and more experimentation would be necessary to draw any further conclusions. Work is being undertaken to create artefact-appropriate XRF calibration standards to assist this work. (Sirois et al, 2007). Factors such as pesticide distribution over the object surface and the porosity of the material under test can affect the results for both types of analysis, and the number of variables is so large that direct comparison of the results gained by each analytical method is currently unrealistic.

The analytical methods under discussion give an indication of what pesticide residues are present on the surface of an object. Translating the results of analysis into quantitative amounts of pesticides residues on the surface of an object, and evaluating the risk that these might pose to museum staff and researchers is virtually impossible. The results of the tests have been passed to the Oxford University Department for Occupational Health, which is currently evaluating them. The only levels that have so far raised concerns are those for lead, and selected museum staff will have tests to determine their blood lead levels as a result. Otherwise, staff will carry on using PPE such as disposable nitrile gloves, lab coat and dust masks (FFP3) when handling objects, and assuming that all museum objects are contaminated with pesticide residues.

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