# ARSENIC AND PRE-1970S MUSEUM SPECIMENS: USING A HAND-HELD XRF ANALYZER TO DETERMINE THE PREVALENCE OF ARSENIC AT NATURALIS BIODIVERSITY CENTER

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*Abstract*.—The use of arsenic in the preservation of biological specimens was common practice prior to 1970. Because the Naturalis Center for Biodiversity (Naturalis) has extensive collections from before 1950, it was suspected that it held many contaminated specimens. In 2013, Naturalis tested 220 objects for the presence of arsenic over a period of 2 days using a handheld x-ray fluorescence analyzer, which detects arsenic, lead, mercury, and some other metals on objects. This testing provides an estimate of the prevalence of contaminated specimens, as well as a way to determine whether arsenic had spread into noncollection areas. In addition to specimens, floors, desks, keyboards, gloves, elevators, and lab coats were tested for arsenic presence and quantity. The results indicate that mounted specimens do not spread large amounts of arsenic onto the surrounding areas. However, there was sufficient contamination to warrant concern such that the arsenic-handling policy was modified to include different categories of contamination. From this framework, policy and physical changes to the building were made to minimize exposure by collections staff and visitors.

*Key words*.—Arsenic, XRF detector, contamination

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## Introduction

Arsenic was a common preservative of biological material at Naturalis Center for Biodiversity (Naturalis) for many years prior to 1970. The first museum director, Coenraad Jacob Temminck, published a manual that described arsenic use and the preservation of specimens in a manuscript dating from the late 1800s (Temminck, zoology manuscript, Naturalis archives). Even older records describe how to use arsenic from Hermann Schlegel, the first known conservator (Schlegel, untitled manuscript, Naturalis archives). Using these documents combined with conversations with older staff about historical preparation techniques, as well as visual inspections of specimens, a large number of specimens were suspected to be contaminated with arsenic.

In 2012, a museum-wide health and safety study was conducted that found multiple safety issues. Based on the results, the Naturalis management team decided that reducing exposure to arsenic via the handling of museum specimens would be a top priority going forward. Furthermore, Naturalis was embarking on an enormous collection digitization project, wherein technicians were to begin digitizing vertebrate mounts and study skins, many of which were suspected to be contaminated. The toxic effects of arsenic on humans are well known, and the hazards museum workers face from handling contaminated specimens are documented extensively (Muir and Peace 1981, Sirois and Taylor 1988, Sirois 2001). This data entry project highlighted a need to ensure the safety of those handling possibly contaminated collections. The goal of this pilot study was to understand which specimens had arsenic and, more importantly, to determine whether and where arsenic might be spreading inside and outside of the collection depots in order to minimize contact by museum workers.

Many museums in the natural sciences, as well as the arts, have been using x-ray technology for years to test for arsenic and other pesticide residues (Sirois and Taylor 1989,

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Sirois 2001, Odegaard et al. 2006). The advantages of this method include 1) the non-invasiveness, speed, and ease with which readings are taken, 2) files are easily downloadable to Windows software, and 3) portability (Odegaard et al. 2006, Bacon et al. 2011). However, some limitations to the technology have been found. The x-ray fluorescence (XRF) detector cannot determine whether arsenic is on the interior or exterior of the specimen (Üstün 2009). Also, the concentrated beam may produce a false negative reading if the specific area of the specimen tested has no arsenic, though arsenic may be found in other areas of the same specimen (Sirois and Sansoucy 2001).

Using the XRF detector, specimens were tested to determine how long ago arsenic was used in taxidermy and if a cutoff year could be identified after which specimens could be considered "safe." We also hoped to discover the extent of arsenic usage and whether it was more prevalent with certain taxa. Furthermore, it was possible that certain preparators used it more than others.

In addition, noncollection objects were tested (study skin drawers, specimen shelves, collection space floors, mount bases), work objects (gloves, lab coats, keyboards), and areas outside of collection spaces (offices, elevators) to establish whether the arsenic was being transferred out of collections and around the museum.

## Methods

A Niton XL3t handheld (XRF) spectrometry analyzer was rented for 2 days from XTAC Analytical B.V. The company provided the detector, a laptop for recording the data, a technician to instruct museum staff on how to use the system, a Geiger counter, and full length lead aprons. The entire system is customizable to the elements of interest, as well as how long each reading takes. We tested primarily for arsenic but also searched for lead and a few other heavy metals. XTAC Analytical recommended taking readings for 15 sec, but Naturalis staff chose 30 sec because most literature recommended longer readings (Sirois and Sansoucy 2001). The detector can be used alone or in conjunction with a lead box designed for focusing x-rays on extremely small specimens. The resulting data files are named by the user and imported directly into a linked Excel spreadsheet, which can later be exported. The XRF detector was already calibrated to manufacturer Thermo Scientific's proprietary "Fundamental Parameters Analysis," and recalibration during testing was not necessary (XTAC staff, personal communication).

The Niton XL3t XRF analyzer consists of several parts: an x-ray tube for exciting the x-rays, a 50 kV tube for the Niton XL3t 500 series, which allows for faster testing (Thermo Scientific 2010), and a pre-amp detector, and a digital signal processor for recording and analyzing the fluorescence produced by the atoms. XRF spectrometry involves detection and measurement of the transitions produced by the elements in a sample when they are illuminated by x-rays produced by the tube in the detector (Glinsman 2005). When the x-rays excite the elements in a sample, each element produces a unique pattern as it transitions from grounded to excited state (Glinsman 2005). The detector and processor read and quantify these patterns for ease of interpretation by the user (Thermo Scientific 2009). The results are produced on the screen of the XRF detector and then are automatically transferred to an Excel spreadsheet on the accompanying laptop.

Radiation is produced by the x-ray tube. Therefore, users wore lead aprons, and a lead-lined test box was used for small objects. A team of two facilitated the process: one person operated the detector, while the other operated the laptop.

A list of specimens to be tested was generated prior to the arrival of the detector. Specimens were chosen based on a number of factors: 1) Preparators—Over the course of

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Table 1. Specimens tested.

| Collection objects in collection depot | Number of specimens | Number of readings |
|---|---|---|
| Mounted specimens | 14 | 22 |
| Study skins/flat skins | 22 | 31 |

Naturalis's history, primarily three different taxidermists have prepared the majority of specimens in the collections: Max Bartels, Henri Jacob Victor Sody, and Willem Cornelis Van Heurn. A selection of specimens prepared by each individual was tested. 2) Visible Signs of Contamination—Specimens with visible signs of contamination, such as bird feet wrapped in cotton that, upon removal, released copious amounts of white powder, mole flat skins, or bird skins that left white powder in the bottom of the box in which they were housed were subjected to testing. 3) Waterfowl—Waterfowl are notoriously greasy and if not cleaned thoroughly during preparation can be susceptible to insects, making them a good candidate for heavy arsenic application (Naturalis preparators, personal communication). 4) Mounted apes—Fifteen years ago, a conservation project of several mounted apes included extensive cleaning. By testing these specimens that were known to have been treated with arsenic prior to cleaning, we could demonstrate how well the cleaning process had been. We also tested mounted animals in exhibit halls and their bases although museum records indicated that exhibit specimens did not contain arsenic.

Work objects tested included dust from a vacuum filter, door handles, lab coats, and the floors in offices, collection depots, and the hallways that connected offices and collection spaces. Work spaces were tested after staff had worked with material that was suspected to be contaminated. Finally, the desks of people that handle suspected dry vertebrate collections material every day were tested, specifically the areas of a staff photographer and a recently retired mammal researcher.

Over the course of 2 days, we conducted more than 220 tests. Some readings were discarded due to operator error and/or the XRF detector freezing up. Sixty-eight readings were done on specimens (Table 1) and 152 on work objects (Table 2). In most cases, multiple readings were taken, particularly when testing floor corners, areas under tables, and high-traffic areas were tested. Typically we took two readings per specimen, one on the dorsal side and one on the ventral side. However, when white powder was detected on a specimen, then a reading was taken on that area as well. Flat skins were tested only once.

Table 2. Work objects tested.

| Work objects | Number of objects | Number of readings |
|---|---|---|
| Floors | | |
| Collection areas | 3 | 5 |
| Noncollection areas (offices elevators, exhibits, etc.) | 7 | 14 |
| Work surfaces and chairs | | |
| In collection depots | 5 | 8 |
| Noncollection areas | 15 | 33 |
| Door handles, elevator buttons | 8 | 10 |
| Protective clothing (lab coats, gloves, masks) | 10 | 16 |
| Keyboards | 3 | 7 |
| Specimen boxes and drawers, collection depot shelves | 9 | 11 |
| Dust from vacuum filter or specimen cabinet filter | 7 | 7 |
| Carts for moving specimens | 4 | 7 |

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Table 3. Testing results with contamination categories.

| Contamination category | Arsenic (parts per million) | Number of specimens tested | Number of work objects tested | Total objects tested |
|---|---|---|---|---|
| Negative | 0 | 9 | 108 | 117 |
| Minimally positive | 1–20 | 6 | 7 | 13 |
| Moderately positive | 21–150 | 11 | 21 | 32 |
| Light to moderate contamination | 151–1,000 | 9 | 14 | 23 |
| Very contaminated | 1,001–10,000 | 21 | 2 | 23 |
| Extremely contaminated | 10,001–25,000 | 12 | 0 | 12 |

Readings were divided into the six categories according to the ppm readings:

1. C1 = Negative Reading: 0 ppm, no arsenic was present or levels were too low to be detected at the sampling sites.
2. C2 = Minimally Positive: 1–20 ppm, which is less than the acceptable amount of arsenic found in the soil of residential neighborhoods in the USA (Belluck et al. 2003).
3. C3 = Moderately Positive: 21–150 ppm. This level is below what the US Centers for Disease Control considers to be immediately dangerous to life and health (US Centers for Disease Control, Agency for Toxic Substances and Disease Control 2007a).
4. C4 = Light to Moderate Contamination: 151–1,000 ppm. These levels are much higher than the levels that naturally occur in soil or water (US Centers for Disease Control, Agency for Toxic Substances and Disease Control 2007a).
5. C5 = Very Contaminated: 1001–10,000 ppm. Prolonged exposure to these levels can lead to an increased risk for cancer and other hazards (US Centers for Disease Control, Agency for Toxic Substances and Disease Control 2007b).
6. C6 = Extremely Contaminated: 10,001–25,000 ppm. Specimens with these levels are very dangerous and must be handled with extreme caution.

## Results

Overall, contamination levels of work objects were much lower than in the specimens (Table 3). Many gloves, lab coats, and work spaces tested negative, despite the fact that contaminated objects had been handled in these areas. Many specimens tested positive, which was expected based on Naturalis records.

The majority of the work objects tested fell in C1, including all exhibits areas, lab coats and masks, keyboards, carts used for moving specimens, and most floors and furniture.

All specimens prepared since 1980 were negative for arsenic. A few older specimens, which had tested negative on the dorsal or ventral sides, produced a contaminated result in the second reading and were categorized in a higher category of contamination.

Three boxes, all of which housed contaminated specimens, had arsenic levels in the C2 range. In addition, the filters mounted in the doors of specimen cabinets where large vertebrate specimens are stored also tested Minimally Positive. Nitrile gloves used to handle moles with >6,000 ppm and the floor in the collection personnel elevator were in this range. Specimens that were mounted by a prolific taxidermist (H. J. V. Sody) from 1910 to 1930 also scored in the C2 range.

The workplace objects in the C3 range included coated cotton gloves that had been used extensively while moving objects in the collection, buttons on the inside of the

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elevator in the collections tower, some shelving units that hold mounted animals in the collection, and work areas of long-term staff members who handled specimens (excluding desk surfaces, which are regularly cleaned). Only three specimens tested in this category: two study skins of European blackbirds, a mounted lesser false vampire bat, and the flat skin of a reticulated python.

The vertebrate collection office floors, both before and after cleaning, produced readings in C4, the 151–1,000 ppm range. The buttons in the collection freight elevator, as well as some of the doors between collections and other areas were also in this category. Specimens that tested in this range included the flat skin of a crab-eating raccoon, a brant goose, a very old gorilla mount that had undergone conservation 15 years ago, a Galapagos giant tortoise, and two different ducks in the genus *Anas*.

A lid from a box of extremely contaminated European mole flat skins tested in the C5 range. In addition, 21 specimens of various ages and taxa fell into this category, although all of the specimens were prepared prior to 1979.

Although no workplace objects scored in C6 range, a number of bird and mammal specimens dating as recently as 1970 did. The most contaminated specimen tested were the feet of an osprey prepared by Bartels in 1927, at 20,000 ppm.

## Discussion

Testing revealed a number of examples where the specimen was highly contaminated, but the surrounding area where the specimen had been prepared was less so. For example, a mounted Rufus-necked sparrow hawk contained more than 7,000 ppm of arsenic, but the shelf where it sat had less than 60 ppm. A wild boar mount from 1896 tested at 13,000 ppm, but the storage shelf read under 100 ppm; a study skin of a blue tit with 5,000 ppm of arsenic was housed in a box the bottom of which read only 12 ppm. The mounts had sat on the shelves for 15 yr (since the building was constructed), and the blue tit skin had been in the box less than 3 yr. Sirois and Taylor's 1989 study found more arsenic inside than outside the skins and also stated that arsenic moves through skins at a rate of 3 cm per 20 yr (Sirois and Taylor 1989). On the basis of these findings, perhaps our specimens have not been in their current locations long enough to have highly contaminated the area around them. The osprey with heavily white powdered feet that tested at 20,000 ppm and a dorsal body side that read nearly 13,000 ppm was in a box that tested below 800 ppm. This higher level of arsenic in the box relative to the shelves of the sparrow hawk and boar may be because the feet are externally powdered and also because the specimen was in the box for nearly 20 yr.

The lid with C5 arsenic levels from the box of European moles may have been a result of carelessness during data entry. The lid of this box was used to hold temporarily specimens, as the technician worked on the other specimens in the box. These skins registered $>$22,000 ppm of arsenic, whereas inside the box where the moles skins were housed registered $>$4,600 ppm. Because each specimen was removed from the box, placed on the desk during data entry, and then placed in the box lid while the remaining moles were processed, the lid was likely contaminated by 70 skin specimens. A second box lid from the same series of contaminated mole skins read only 90 ppm, while desk, keyboard, and lab coat and gloves used for this project ranged from 0 to 5 ppm.

Of the three prolific taxidermists whose work was tested, two, M. Bartels and W. C. van Heurn, produced specimens with extremely high levels of arsenic. However, specimens prepared by H. J. V. Sody, who was a contemporary of the others, contained much less arsenic, which indicates a sparing use of the toxin. Birds and mammal mounts and

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study skins were more contaminated than dry reptiles and amphibians. A definitive date when arsenic was no longer used could not be determined, although it appears that usage declined in the early 1970s and was not used at all after 1980.

A series of mounted apes had undergone conservation treatments 15 yr ago to remove all traces of arsenic. The recent reappearance of a white powder at the seams caused concern. Testing revealed that some of the gorilla seams were lightly contaminated, which suggests the conservation work was unsuccessful in removing all of the arsenic, and these mounts must be handled accordingly.

There was some discrepancy between how much arsenic museum records and conversations with preparators indicated would be on specimens and the actual amount of arsenic found on specimens. Arsenic was believed to have been painted over the entire inside of some specimens. However, there was no consistency as to whether the dorsal side or the ventral side of a specimen was more contaminated, although one side was often much more contaminated. Clearly, not every taxidermist applied arsenic in the same way. It is possible that this reflected the limitations of the XRF detector, which has difficulties reading uneven areas (Found and Helwig 1995).

The office of a recently retired curator was tested for arsenic, although his workspace had been cleaned by housekeeping. Everything in the office tested Negative, except for inside the metal bookcase, where he had stored the specimens with which he was actively working. The bookcase registered 93 ppm (C3 levels), whereas the top of that same bookcase read 81 ppm. The desk of our staff photographer, who frequently works with specimens in his area, was completely clean of arsenic. These results indicate that regular house cleaning services removes arsenic, but this then indicates that housekeeping staff is coming in contact with hazardous substances and has led to changes in housekeeping practices.

The laboratory floors, which double as office space, have a special type of nubby coating that is designed to be antiskid in the case of spilled liquids. This porous coating had category C4 contamination, at 415 ppm, both before and after cleaning. Clearly, there has clearly been arsenic buildup that permeated the floor during the 15 years this building has been in existence. Although some construction materials contain arsenic, this floor coating did not (Naturalis records). Of greater concern was the arsenic 125 ppm reading on the underside of the registrar's purse, which she frequently kept on the floor by her desk. This is potentially dangerous because of the possible transference of arsenic to her home.

The buttons on the inside of the collections tower elevator registered in the C4 range. This is probably due to the recent completion of a giant multiyear merger of three museums. Specimens were packed, unpacked, and moved around all the collection spaces. It is unclear if the elevator, which may have been contaminated from dirty gloves pressing the buttons, was cleaned during that time.

### *Implementation of Results*

Due to the small sample size of the study and the limitations of the XRF detector, the decision was made that any specimen that tested above 150 ppm would be considered high risk and should be handled as such, although US OSHA limits are 200 ppm based on laboratory exposure (US Labor Department, Occupational Health and Safety 2012; US Centers for Disease Control, Agency for Toxic Substances and Disease Control 1998).

New collection protocols dictate that recent preparations be stored separately from older contaminated or suspect specimens and that gloves and a buttoned lab coat must be

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worn when handling specimens of any age. After handling specimens, even with gloves, hands must be washed according to proper instructions. When removing specimens from the collection area, only specific low-traffic elevators and hallways are to be used. All areas where specimen traffic occurs are regularly cleaned. Cleaning staff must also wear buttoned lab coats and nitrile gloves while cleaning high-risk areas with special disposable one-use wipes. There are new procedures for handling contaminated trash and used lab coats as well. The trash is disposed of with other hazardous waste, and the lab coats are washed by an outside firm that deals specifically with unsafe laundry.

A special room was constructed for people working with high-risk specimens. This room has special, easy-to-clean surfaces and keyboards and very strict rules for use. Anyone using this high-risk space must first read and sign the manual of best practices, which includes no food and drink and requires buttoned lab coats and gloves. Non-essential personnel and immunocompromised individuals, including pregnant women or people with open wounds, are not permitted in this room. There are special procedures for disposing of dirty coats and gloves, and the room is cleaned more frequently and more thoroughly.

The findings from this study also resulted in the decision to separate physical work and lab spaces. Personal items, such as coats, bags, hats, etc., are not allowed in laboratory spaces, which no longer double as offices. Hence, areas where coffee is consumed are not the same places where specimens are handled. As part of a larger building renovation, the floors in the laboratories will be replaced in 2016.

Floors in our collection areas were vacuumed during testing; the dust in the filters tested negative for arsenic. An outside company tested work space air in 2014 and confirmed that our air is safe.

More testing is still necessary to map the exact presence of arsenic in the collection. Many preparators have prepared many objects for the collection, but only objects prepared by the most prolific taxidermists were tested. In addition, though the use of arsenic ended sometime between 1970 and 1980, the exact year is unknown. Further testing could illuminate this.

Many other organic pesticides are likely to be found in museum collections (Williams and Hawks 1987), but this directive focused primarily on arsenic. A more comprehensive study is necessary to isolate parts of specimens that are arsenic rich and should involve more than two readings per specimen.

Finally, Naturalis's collection is distributed throughout multiple buildings, although the testing for this study was restricted to the main building, where staff offices are located. In three years, the ungulates and whales, which are currently housed elsewhere in the city, will be moved into the main collection building. At that time, an additional study will be carried out to determine the contamination status of those collections.

## Conclusion

This pilot study was conducted to determine the presence and amount of arsenic on Naturalis specimens prior to 1980, as well as the prevalence of arsenic in noncollection areas. Most specimens registered in the lower categories of arsenic pollution. Overall, arsenic contamination levels of work objects were much lower than of specimens. In addition, it appears that specimens do not spread much arsenic. Nonetheless, there was enough of a contamination concern that our arsenic-handling policy was modified by creating a high-risk category of contamination. These new guidelines minimize contact between staff and arsenic as well as keep contamination of noncollection areas to a minimum.

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