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Author(s): Jan Freedman

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Safe Handling and Storage of Potentially Hazardous Minerals in Natural History Collections.

Jan Freedman

Curator of Natural History,
Plymouth City Museum & Art Gallery,
Drake Circus, Plymouth, PL4 8AJ

Email: jan.freedman@plymouth.gov.uk

Abstract

Minerals in museum collections may pose potential hazards to curators and visitors. This paper discusses the background and use of radioactive minerals and asbestiform minerals, providing examples of safe handling and storage techniques. Toxic elements are also discussed using examples of the more common elements and associated minerals to be found in museum collections including arsenic, mercury, lead and antimony. Historical and current uses of these elements are discussed, along with adverse health affects. Developing a clearer understanding of specimens held in collections allows them to be handled safely, and reduces the common fear of potentially hazardous specimens.

Introduction

Natural history collections contain numerous hazardous components, of which the curator must be wary of, which include man-made compounds and naturally occurring minerals. Minerals formed through geological processes in the Earth's crust can be both beautiful and potentially hazardous. Geological collections present some obvious hazards, which can be identified almost immediately. For example, some minerals may be sharp and rocks, by their very nature, are heavy, resulting in potential problems with unlabeled boxes in geological store rooms (Knell & Taylor, 1989). These two examples are mitigated against relatively easily, as they are simple hazards to identify. However, the hazard of any mineral depends on the specimen itself (Lambert, 1994a); it may depend upon the chemical composition, the solubility and/or form of a specimen.

Generally, minerals with a large crystal structure are more stable and safe, because they are less likely to be ingested. Friable specimens may present more of a risk leading to airborne particles which may be ingested or inhaled (Knell & Taylor, 1989). For example, quartz is generally considered a safe and stable mineral, but it is classified as harmful as prolonged exposure to airborne dust produced through grinding can lead to the lung disease silicosis (HSE, 2002a). However, the risk to the average curator is minimal, unless they are grinding and polishing specimens, where the risk can be reduced considerably using water to suppress the dust. As many of the regional and smaller museums do not have the facilities to undertake geological laboratory work, this paper will focus on the day to day curation of geological specimens. (Further information regarding safe working practices with laboratory preparation work can be found on www.hse.gov.uk)

The curator has a responsibility to safeguard themselves, visitors to the collections, members of the public and future museum staff against the possibility of any risk from the collections. Safely handling them, updating documentation, and safe storage will reduce this risk against potentially hazardous specimens. Understanding the background to the specimens and how they can be safely handled and stored is important to minimise any possible risk. Present health and safety precautions should always be treated with respect, but a knowledge of the collections will allow research to be undertaken, which is vital to ongoing scientific knowledge.

Potential pathways to problems

Care is needed when handling specimens as there are three main routes of exposure; inhalation, ingestion and absorption. Each can be simply mitigated against to reduce any risk;

- **Inhalation** is the breathing in of particulates or vapour produced from the specimen. This can include airborne dust created from handling or transporting specimens. The risk of inhalation is increased when working directly with friable specimens in enclosed areas. Personal Protective Equipment (PPE), such as a dust mask can reduce the risk and if working directly with a specimen working within a fume cupboard would minimise the risk further and reduce the likelihood of airborne particulates in the work space.

- **Ingestion** can occur if particulates from the specimens enter the mouth, which is more likely from handling mineral specimens that are extremely friable. The majority of minerals are inert to stomach acid, and will pass straight through the body with no adverse effects (Cotterell, *pers comm.* 2011), but it is important to know those which are not. Some minerals are water soluble and can be identified by taste, such as the mineral halite, but the curator should always be cautious and never lick unidentified specimens (Brunton, *et al.* 1985; Knell and Taylor, 1989), particularly as there are some poisonous minerals which are water soluble. Particularly harmful soluble minerals should be highlighted with precautions and with medical advice in case of ingestion. Identification of minerals through taste is an old method, still taught in A-Level and University Geology courses; however, it is highly recommended that curators do not lick their specimens. The risk of ingestion can automatically be reduced, or eliminated, by using disposable gloves if handling the specimens and washing hands directly after use.
- **Absorption** is when a mineral is absorbed directly through the skin, or through a lesion (cut or abrasion) in the skin. Although less of a potential risk to the curator, some specimens, such as mercury, may be absorbed directly through the skin (although the main hazard from mercury is from heating the native element producing the vapour methyl mercury). The soluble, and very toxic form of arsenic, arsenolite, can be absorbed through the skin. Absorption can be minimised by wearing disposable gloves and washing hands immediately after use.

A hazard can be defined as something that has the potential to cause adverse affects to the human body (HSE, 2011). In terms of geological collections, potentially hazardous minerals can be broken down into the following groups (after Lambert, 1994a);

- Radioactive minerals
- Asbestiform minerals
- Toxic minerals

Radioactive minerals

Museums holding mineral collections are likely to contain some radioactive specimens. Lambert (1994b) suggests that as much as 10% of a mineral collection will be radioactive; however, the number of radioactive specimens will depend upon historical collecting policies and on the geological history of the local area.

The force binding the protons and neutrons together in the nuclei of stable atoms (such as lead) is strong enough to hold together each nucleus as a whole. In uranium and thorium, however, this energy is not strong enough and the nuclei are unstable, resulting in energy and particles being emitted (Ellis, *pers comm.*, 2011). Radioactivity can be defined as the break down of atoms, resulting in lighter atoms being released emitting alpha, beta and gamma rays (Brunton, *et al.* 1985).

There are a variety of names for different radioactive minerals which the curator should be aware of, the more common being, autunite, torbernite, meta-torbernite, saleeite, meta-saleeite, uranophane and uraninite [synonym of pitchblende]. ‘Meta’ before a mineral name means the specimen is ‘meta stable’; so meta-torbernite has lost a small proportion of its water of crystallisation compared with torbernite. There may be other mineral specimens in collections, which have radioactive elements in; for example bismuth can be associated with uranium ores, but is not itself radioactive. The original specimen labels need to be examined and the information updated with the specimens and the museum database. Historical labels may not state whether there is any radioactive material associated with the ‘main’ mineral, and it is recommended to test the entire mineral collection with a Geiger Counter.

Radioactive specimens do present possible risks to staff and visitors, because specimens can emit invisible alpha, beta and gamma radiation, as well as emitting radon gas that can build up in store rooms; prolonged exposure to these types of radiation can cause severe health problems. (Radon gas has a short half-life, so will only build up in the store if there is poor ventilation.) There may be additional risks if specimens are friable, leading to an increased risk of the fine particles being inhaled or ingested (Henderson, 1982).Sec-

ondary uranium minerals are particularly friable, as they have a tendency to form platy or acicular crystals in crusts. Uranium can be transported through groundwater leaching of primary uranium oxide minerals with redeposition in a different location (Dixon, 1983). Secondary uranium minerals generally have less uranium content, than primary uranium phases as they occur as complex hydrated phosphates, sulphates, carbonates and silicates while some of the uranium will be carried off in the groundwater.

The inhalation and/or ingestion of radioactive particles is significantly more dangerous than handling the specimens directly; human skin is made up of cells which are replaced daily, but if the material is ingested or inhaled, the alpha radiation can bombard the live cells inside the body (Cotterell, *pers comm.*, 2011). This obviously depends on the dosage received; the Russian military who cleaned up after the Chernobyl incident received enormous doses of radiation in a short space of time and died shortly afterwards (Marples, 1996).

The Radioactive Substances (Geological Specimens) Exemption Order (1962) allows the storage of up to 100kg of uranium and thorium, and most, if not all, museum mineral collections will be below this limit, so will not need to register under the Environmental Permitting Regulations, 2010. However, there are guidelines for safely working with radioactive materials which are outlined in the Ionising Radiations Regulations, 1999 (IRR99). The guidelines cover different work settings, from working with X-Ray machines to the nuclear industry, but the key recommendation for all work settings is the same; to keep radiation doses 'As Low As Reasonably Practicable' (ALARP).

Measurements of radiation levels are usually expressed in microsieverts per hour ($\mu\text{Sv h}$) or millisieverts per hour (mSv h) and this can be measured with a standard Geiger Counter. The maximum level of $2.5 \mu\text{Sv h}$ is recommended outside a radioactive store where there is general employee access (IRR99). This is the recommended dose limit, and it must be remembered that there is natural background radiation; the background radiation measured at Plymouth City Museum and Art Gallery on 7th April 2011 was $0.5 \mu\text{Sv h}$. Natural radiation from the sun is higher at higher altitudes, and can result in natural dose rates of $5 \mu\text{Sv h}$ when flying in an aeroplane (Ellis, 2011, *pers comm.*).

It must be remembered that these are recommended hourly dose rate, and measure in *microsieverts* ($1000 \text{ mSv} = 1 \mu\text{Sv}$). The dose rates can be put in perspective with the following example; a curator inspects a radioactive specimen (which measures $30 \mu\text{Sv h}$) for one hour. For 10 minutes of this hour the curator is directly handling the specimen and the remaining 50 minutes is a visual inspection of the specimen. During the 50 minute visual inspection, the dose rate will be reduced (to about a third), as the curator is further away from the specimen. The radiation uptake would be $5 \mu\text{Sv}$ for directly handling the specimen and $8 \mu\text{Sv}$ when inspecting the specimen. So the total radiation uptake for one week would be $13 \mu\text{Sv}$, and so the total uptake for a year, if carried out for one hour of each week in a year, would be $700 \mu\text{Sv}$. The yearly example is under the recommended maximum dose levels for employees in one year, which is 20 mSv (or $20,000 \mu\text{Sv}$) (IRR99).

Different museums will store their radioactive specimens depending on their funds available, space available and advice given (Freedman, 2011). For example, Dundee's Art Gallery and Museum, The McManus, have stored their radioactive material with advice from the Scottish Radiation Protection Advisor. Their collections, including mineral specimens and luminous watch dials, are stored in Perspex boxes, in a labelled drawer within the main museum collection (Lampard, 2010, *pers comm.*). This solution at The McManus kept the risk ALARP for their collections and their staff. The National Museum Wales, Cardiff, had to undertake a different solution. After separating the radioactive minerals into a 'radioactive bay' in the main store, and monitoring radon levels in the store room, it was decided that a Designated Store would be more suitable for the collection (Lambert, 1994b). The new store, which holds all the radioactive specimens, has restricted access and has built in extraction to remove any radon gas to the outside of the building (Lambert, 1994b). Freedman (2011) notes several other examples of storage solutions to large and small radioactive collections.

Plymouth City Museum and Art Gallery (PCMAG) holds over 10,000 mineral specimens of local and historical importance, including 139 radioactive specimens. All the mineral specimens were stored in the Hey (1962) cataloguing system in the main mineral store, which also holds other natural history, archaeology and social history collections. PCMAG contacted a Radiation Protection Advisor (RPA) to assess the radioactive collections and to make recommendations for the storage of the radioactive specimens, to reduce any risk in line with ALARP. If measured levels outside storage cabinets exceed $7.5 \mu\text{Sv h}$, it is recommended

to use a Designated Area/Store, which is a restricted area holding the radioactive specimens (IRR99). The radon levels were measured just above this limit at PCMAG, (8 μ Sv h), so it was recommended to store all the radioactive specimens in a Designated Area away from the general public and from other members of staff (Freedman, 2011).

All the minerals are stored in acid free card trays in wooden drawers, and the radioactive minerals were stored in clear zip-lock bags limiting the alpha radiation being released (Henderson, 1982), but the particulates in the bags could potentially be released into the work space if opened. Before being transferred to the new Designated Area, all the radioactive specimens were repacked in clear polystyrene boxes, so the specimens were clearly visible, and lined with *Plastazote*, to reduce any abrasion of the specimen (Fig. 1). All repacking was carried out in a fume cupboard, with appropriate PPE, including respiratory mask, disposable gloves and disposable aprons (Henderson, 1982; Brunton, *et al.* 1985; Mast, 1996; Wilson, 1996). The specimens have been transferred to new yellow metal cabinets (Fig. 2). The outside of the drawers of the metal cabinets have been labelled with magnetic tape, which will allow for specimens to be moved with ease in the future, and it is clear what drawer holds what specimen.



Fig. 1. Torbernite specimen re-packed in clear polystyrene plastic container, with *Plastazote* lining. The associated labels are facing outwards to minimise any disturbance of the specimen.



Fig. 2. One of two new metal storage cabinets. The drawers are labelled on the outside with the specimen name, number and collector. The labels are magnetic tape, which will allow easy move in the future if necessary.

Transferring the specimens into new clear polystyrene boxes allowed an opportunity to limit double handling of the specimens and safely digitally image them. Each specimen was imaged with its associated labels on a shallow tray, which was subsequently cleaned with a damp cloth to remove any particulates (Henderson, 1982; Mast, 1996). The images have not only been attached to the specimen record on the museum database, they have also been used to create a 'hand-guide' of the specimens in the new store. Highlighting the specimen number, name, locality, collector, and which cabinet and drawer it is stored in, the hand-guide has further reduced the need of obtaining information directly from the specimens, and dramatically reduces the time in the store if direct examination is required.

Asbestiform minerals

Asbestos is the name used for a group of naturally occurring fibrous minerals formerly widely used in industrial application. Asbestos itself, means 'unquenchable', referring to its resistance to fire. There are two groups of asbestiform minerals; those with a serpentine structure and those with an amphibole structure. Chrysotile (white asbestos) is a serpentine group mineral, with twisty and curly fibres, and was the most widely used form of asbestos. Crocidolite (blue asbestos) is a variety of riebeckite, and amosite (brown asbestos), is a variety of the mineral grunerite, and are both amphibole forms. The amphibole forms of asbestos generally produce sharp, brittle fibres and are significantly more hazardous than the serpentine group (Skinner, 2003; National Cancer Institute, 2009). Actinolite, tremolite and anthophyllite are other amphibole group minerals that can occasionally form fibres suitable for industrial application as asbestos (Cotterell, *pers comm.*, 2011). Asbestos fibres can be long (up to 30cm) and very thin (0.01-0.40µm in diameter) (Wachowski & Domka, 2000).

The popular mineral Tiger's Eye is formed by successive growth layers of quartz and crocidolite, but because of its compressed and solid form, it does not pose any risk to the curator so there is no need to treat these as hazardous specimens. However, a technician carrying out cutting of specimens should be aware of the potential risk from crocidolite and the appropriate laboratory health and safety guidelines should be followed.

Each asbestiform mineral has different properties and as such is used for different purposes. The mining of chrysotile, amosite and crocidolite for large scale industrial use began in the 1880s (Gee & Greenberg, 2002). Asbestos has been used for building insulation and to insulate steam engines, and has been used in over 3000 products, including cardboard, plastics, felt, paper, protective suits, roofing, blankets, electrical insulation, and floor tiles (Wachowski & Domka, 2000; National Cancer Institute, 2009.). The use of asbestiform minerals for heat resistant products is not new; 4000 years ago, asbestos was used to make ceramic dishes more heat resistant (Wachowski & Domka, 2000). Mattenklott (2007) has analysed commercial soap stones and talcum powders demonstrating that asbestos can be found in very small quantities in about one in four of the samples investigated. The list of products is important, because social history collections in museums may hold objects which could contain processed asbestos. Examples of refined or partly refined asbestiform samples may be found in mineral collections; these may be more hazardous than the natural specimens, as they have been processed, so will contain smaller and finer particles (Mattenklott, 2007).

Fibres of asbestos are present in the air due to natural erosion and from industrial processes and sewage and water pipes; interestingly, the natural processes producing airborne fibres is greater than that of man made production (Wachowski & Domka, 2000). After mechanical processing, it has been noticed, that asbestos fibres are even smaller and finer (Mattenklott, 2007). New asbestiform carbon-type fibres are produced by industry for industrial and even telecommunications use (Skinner, 2003), which may add new types of particulates to the air.

Health risks of asbestos inhalation depends upon the type of mineral, the size of the inhaled fibres and the time of exposure and usually takes about 30 years for symptoms to show (Wachowski & Domka, 2000; National Cancer Institute, 2009). Health risks will increase with larger exposures of asbestos and longer exposure times. Fibres between 1µm and 10µm long, and less than 3µm diameter, will be deposited in the air sacs in the lungs; fibres less than 1µm are easily inhaled, but they are so small that they cause little effect inside the body; fibres longer than 10µm are inhaled, but are stuck on the mucus membrane and do not reach the air sacs (Hume & Rimstidt, 1992; Wachowski & Domka, 2000). Prolonged inhalation of asbestos fibres can cause some cancers, including colon cancer, stomach cancer and the lung disease, mesothelioma (Wachowski & Domka, 2000; Gee & Greenberg, 2002).

Handling and storage of asbestos specimens in collections must be dealt with extreme caution. In 2001, PCMAG undertook a project to safely store the asbestos of over 70 specimens. They were stored in clear zip-lock bags in acid free card trays. The museum contacted the asbestos removal team for Plymouth City Council to assess the collections and make recommendations. Due to the historical importance of the collectors, and the localities associated with the specimens, all specimens were retained. The asbestos removal team offered their assistance in safely storing the mineral specimens.

A sealed tent with air extraction was set up on site, and specimens were brought up from the store room. Fully clothed in PPE, including protective suit, masks, goggles and gloves, the team transferred the minerals into clear boxes, placed the labels on the outside, and then the labels and the box in clear zip-lock bags (Fig. 3). All the drawers holding the specimens, and the labels associated with the specimens, were vacuumed to remove any trace of asbestos particulates. This current storage is not ideal, as the specimens in the clear boxes may move freely in the box causing abrasion of the specimens, and producing more particulates, which could potentially become airborne when the specimen is directly handled. The storage of this collection will be reviewed in the future.



Fig. 3. Chrysotile specimen stored in clear box in zip lock bag. This method was suitable for the funds available at the time, and the storage will be reviewed in the future.

The Royal Cornwall Museum, Truro, recently stored all asbestos minerals in translucent *Escal* sealed bags, with the associated labels sealed separately from the specimen (Fig. 4). The work was carried out in asbestos grade fume cupboards at Cornwall Council's Engineering Services laboratories so they could be sealed safely. All specimens were digitally imaged at the same time to minimise double handling of the specimens (Ratcliffe, 2011, *pers comm.*). The sealed specimens are now stored in card trays in labelled drawers to minimise movement of the specimens (Ratcliffe, 2011, *pers comm.*). This barrier film, sealed shut with a heat sealer, allows the asbestos to be viewed safely without the need of opening the bags and the labels are kept away from contamination of asbestos fibres (Freedman & Lawrence, 2008). Sealed in *Escal*, the specimens are stored tightly in the drawers to prevent movement and physical damage. However, this method of storage does appear to create static resulting in broken fibres being stuck to the inside of the *Escal* packing; this would be hazardous if opened resulting in more airborne fibres being released.

These above two examples work for the institution and the funds available keeping the risk as low as possible. The *Escal* method works very well, as it stops the specimen from knocking other specimens, and it provides a completely sealed environment. However, *Escal* is expensive, and a heat sealer is required to ensure the packing is carried out effectively. Static inside the *Escal* sealed bags can dislodge fibres on the specimen, so extra care is needed if sampling is required directly from the specimen.

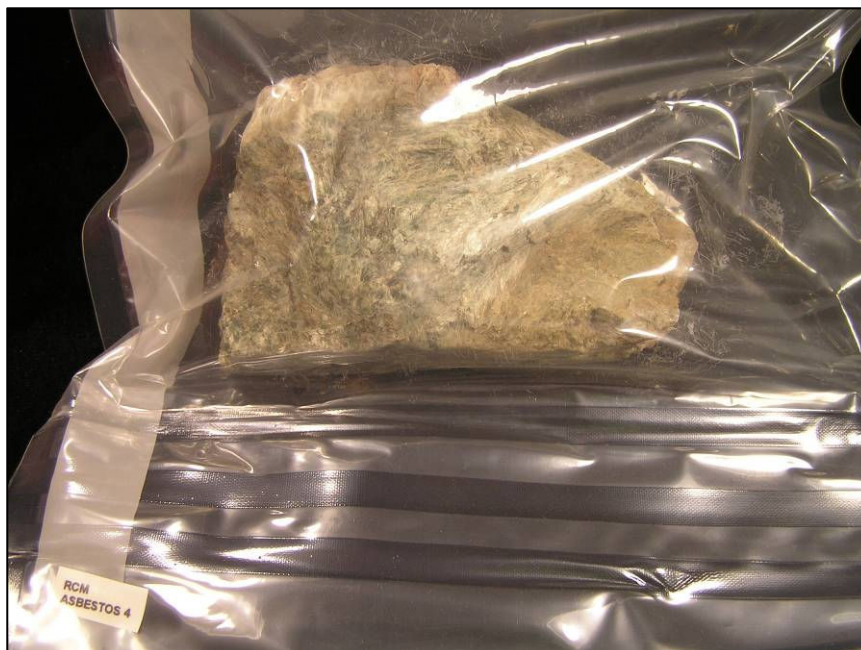


Fig. 4. - Sheaves of long very slender pale green prismatic actinolite sealed in clear Escal packing, it allows the specimen to be viewed from all sides and the label is sealed separately. Note the small fibres attached to the inside of the packing due to static. (Asbestos 002 (RCM Asbestos 4): Image reproduced with permission from the Royal Cornwall Museum, Truro).

All asbestos specimens should be stored in sealed containers (Knell & Taylor, 1989; Lambert, 1994a) and if possible, specimens should be packed well using *Plastazote* to avoid any breakages of the fine fibres creating more dust (Lambert, 1994a). However, even packing specimens in *Plastazote* can dislodge the fibres, so care must always be taken when storing specimens. All storage containers and drawers holding the specimens should be labelled clearly with a warning label (Knell & Taylor, 1989), so other museum staff, visitors, and future museum staff are aware. If undertaking new storage projects of asbestos collections, the curator should contact their local council asbestos removal team, who are specifically trained to safely handle asbestos. Alternatively the curator can contact another museum who has carried out a similar project for advice.

Toxic Minerals

There may be up to 200 mineral species which may be classed as toxic, but in museum collections many of these are not considered to pose any direct danger to staff (Lambert, 1994a). A toxic element can be defined as one which adversely reacts with enzymes in the cell causing damage to the health of an organism, and is in effect a poison (Waites & Harrison, 1999). The chemical composition of minerals may make them more toxic, as they can contain toxic elements (Brunton, *et al.* 1985), so understanding the mineral will lead to a clearer knowledge of safe handling and storage. Elements which are toxic and may be associated with some minerals are antimony, arsenic, bismuth, boron, copper, fluorine, lead, mercury, oxalates, selenium, thallium, uranium and zinc (Brunton, *et al.* 1985). Often, the specific compound itself is more toxic than the element. These toxic elements are extremely rare in their native form and are unlikely to be encountered in natural history collections. It should be remembered that some of these elements may be toxic, but are also important to human health (for example fluoride in toothpaste and added to tap water). The element zinc is required for fertility and calamine lotion is a zinc based treatment for skin problems (Cotterell, *pers comm.*, 2012).

The solubility of a mineral will determine its toxicity (i.e. its ability to dissolve in water). Most minerals are insoluble in stomach acid, so there is no risk of many minerals being absorbed by ingestion, for example barite and galena (Lambert, 1994a); although these two examples contain toxic elements, their actual toxicity through absorption is absent. Some minerals however are highly soluble in water, including rock salt (the mineral halite) which is only harmful in large concentrations, but others, such as potassium dichromate (lopezite) minerals are highly toxic. Chromite, a chromium oxide, and barium are considered harmful elements but are not because they are inert (Cotterell, *pers comm.*, 2011). Baryte (barium sulphate) if ingested does not react with stomach acid and will pass straight through the body; witherite (barium carbonate) specimens however will react with the stomach acid releasing barium into the body (Cotterell, *pers comm.*, 2011).

Below provides some background to the more common toxic elements including arsenic, mercury, lead and antimony, with associated minerals containing these elements, which may be encountered in museum collections. (The general handling and storage of these four examples is the same for the above list of toxic elements, and advice should be sought if unsure about the safety of any specimen in a collection.)

Toxic elements: Arsenic

Geological collections frequently hold mineral specimens containing arsenic, such as the iron arsenic sulphide, arsenopyrite, and the arsenic sulphides realgar (red arsenic) and orpiment (yellow arsenic). Native arsenic is rare in nature, but is often present in older museum collections, particularly those with a strong European influence (Cotterell, *pers comm.*, 2011). Native arsenic may also be present in collections with examples of refined metals and semi-metals, along with the significantly more hazardous, water soluble white arsenic oxide, arsenolite. Many collections will also contain specimens of attractively coloured secondary arsenates of copper, lead and iron, most of which are relatively insoluble. A few examples include lironconite and olivinite (copper arsenates), mimetite (lead chloroarsenate) and scorodie and pharmacosiderte (iron arsenates).

The industrial use of arsenic has concentrated on the arsenic sulphides, arsenopyrite, realgar and orpiment. Arsenic compounds can also be found in minerals, which pose less of a hazard, such as copper, lead, iron and cobalt bearing species (Gorby, 1988; CAREX Canada, 2010). Biological and ethnography collections may contain arsenic powder, which has historically been used as a preservative for bird and mammal skins (Wagstaffe & Fidler, 1968; Knapp, 2000) and can be seen on specimens as a fine white powder (Knapp, 2000). Two arsenic mixtures have historically been used to 'brush' over taxidermy specimens to protect them from insect damage; arsenic-borax powder (50:50 powdered arsenic [arsenic trioxide] and powdered borax [sodium tetraborate]), and arsenic-alum powder (50:50 powdered arsenic [arsenic trioxide] and powdered alum [potassium aluminium sulphate]) (Wagstaffe & Fidler, 1968). Arsenic paste and soap have even been used in the past for fixing and preserving spirit specimens (Carter & Walker, 1999; Knapp, 2000).

Arsenic has a long history of human use; peculiarly for Westerners, as a medicine. Hippocrates advised on using a realgar paste to help cure ulcers (Bentley & Chasteen, 2002). As well as being used as an aphrodisiac in the 19th century, eating arsenic compounds was believed to give 'plumpness to the figure, cleanness and softness to the skin, and beauty and freshness to the complexion' (Bentley & Chasteen, 2002). Prostitutes favoured rubbing arsenic in their cheeks to give a rosy tint, but unfortunately, this lovely alluring appearance is produced by the arsenic damaging blood vessels in the skin (Bentley & Chasteen, 2002). Arsenic derived from soluble sources have been used to produce a solution (known as Fowler's solution) that was used to treat a huge array of medical ailments, including syphilis, and drinking it regularly was recommended to give women a much fairer complexion (Bentley & Chasteen, 2002).

Arsenic compounds have also been used in cosmetics, foods, glass, and insecticides (Bentley & Chasteen, 2002). Currently arsenic use is limited and can be found in wood preservation and used with lead alloys in batteries (Bentley & Chasteen, 2002). Arsenic compounds have been, and are still, used in Chinese and Indian medicines; orpiment is used as a louse killer, a cure for scabies, insect bites and skin diseases; realgar is used for colds, toothaches, asthma, ulcers and, mixed with plants to treat cancer; arsenolite is successfully used to treat cervical cancers and solid tumour cells (Lui, *et al.*, 2008). Arsenolite has successfully been used in Western medicine recently, to treat leukemia (Lui, *et al.* 2008; CAREX Canada, 2010).

Arsenic is present in all living organisms (Gorby, 1988). The recommended levels of arsenic in drinking water are 0.01mg/l (WHO, 2003), but it has been noted that the daily intake in humans is an average of 0.5 - 1mg (Gorby, 1988). Urine samples have demonstrated higher levels of arsenic present after consuming seafood (Gorby, 1988), resulting in higher averages than the recommended levels outlined by WHO (2003). As with any substance, too much can prove fatal, particularly if there is a cumulative intake of arsenic.

Experiments with rodents have shown that the fatal dose is very much dependent on the composition of the ingested arsenic compound (Lui, *et al.* 2008). Orpiment and realgar are poorly absorbed into the body, but arsenolite is more readily absorbed, making it more toxic with a lethal dose of between 32-39mg/kg (Lui, *et al.* 2008). In humans the lethal dose of arsenic oxide is considered to be 100mg (Gorby, 1988). Potential effects of arsenic poisoning include, vomiting, stomach pains, convulsions (Wagstaffe & Fidler, 1968), and long term effects may include liver cancer, lung cancer and cancers of the reproductive organs (Knapp, 2000; CAREX Canada, 2010) and long term effects through ingestion can lead to skin cancer (CAREX Canada, 2010).

Specimens in collections labelled as arsenic, realgar, orpiment, arsenolite and arsenopyrite should always be handled with disposable gloves to minimise any risk of ingestion, or in the case of arsenolite, absorption. Arsenic is quite dense but the flaky nature of realgar and orpiment, and the fibrous and powdery habit of arsenolite, does have the potential to become airborne. If working directly with specimens, a dust mask and gloves should be worn, and work should be carried out in a fume cupboard. The work surface can be wiped down with a damp cloth to pick up any small fragments, which can be disposed of (Henderson, 1982; Mast, 1996).

Ideally, specimens should be stored in lidded containers, with *Plastazote* cut outs to hold the mineral to reduce the amount of movement and possible damage to the specimen. Clear polystyrene boxes will allow the associated labels to be visible inside the box (Fig. 1). However exposure to light can cause realgar to degrade to pararealgar; these specimens can be stored in *Plastazote* lined card boxes, with an image of the specimen on top and some brief information about the specimen on the lid, including identification number, specimen name, locality and collector. This reduces the need to open the box, and in the case of light sensitive specimens, an image of the specimen on the lid reduces the exposure to light. All containers holding toxic specimens should have a 'Toxic' label visible on the outside.

Toxic elements: Mercury

Described as liquid silver by Aristotle (Christie & Brathwaite, 1995), mercury is one of the more interesting elements that may be stored in collections; it is a liquid metal at room temperature, and its freezing point is very low, at -39°C (Waites & Harrison, 1999). Native mercury may be found in geological collections stored in glass vials in its liquid form, but it may also occur as silvery metallic globules on the mineral ore, cinnabar (mercury sulphide). Other mineral specimens which may be associated with mercury are native gold and native silver, and lead-bearing and zinc-bearing minerals (Christie & Brathwaite, 1995).

Ancient Egyptians were using mercury from around 3500 years ago and later the Greeks, Chinese and Romans also used this metal (Christie & Brathwaite, 1995). Perhaps most well known for its historical use in thermometers (which is now banned), it still has many uses today, including used in fluorescent lamps, switches, relays, batteries, paint, blood pressure machines and, alloyed with silver, tin and copper as amalgam, in fillings for teeth (Christie & Brathwaite, 1995). There is no evidence, however, that mercury in fillings has any adverse effect on human health, because the level of mercury used in the filling is small (Mackert, 1987; Olsson & Bergman, 1992; Mackert & Berglund, 1997).

Mercury is used with other metals as alloys, and has been used to extract gold from its ore, before the introduction of the cheaper method of cyanide (Christie & Brathwaite, 1995). Incredibly, in the 19th century, mercury was used to treat an array of illnesses; patients would receive massages rubbing in a mercury mixture in-between injections of arsenic mixtures into the body (Bently & Chasteen, 2002). At the beginning of the 20th century, injections of the mercury 'tonic' were used to treat tuberculosis, even though it was known to have serious cumulative effects (Moseley & Redlands, 1909).

Once inside the body if ingested or inhaled mercury prohibits the function of enzymes leading to stomach ulcerations, bloody diarrhoea and kidney disease (Wagstaffe & Fidler, 1968; HSE, 2002a), and if received in continuous cumulative doses can lead to acute poisoning, including brain, liver and kidney damage (Christie & Brathwaite, 1995; HSE, 2002a). The most infamous example is the methyl mercury poisoning at Minamata Bay, Japan. Methyl mercury, which is produced as a gas through the heating of mercury, is a particularly dangerous form of mercury as it is rapidly absorbed in the gut. As a result of small mercury waste products discharged from a plastics factory, the organisms at the bottom of the food chain received a small dose of mercury. However, further up the food chain, the levels of mercury increased, which resulted in over 2000 local people developing severe mercury poisoning resulting in physical deformities, muscles weakness, and problems with the central nervous system (Skinner, Porter, & Botkin, 1999). It is highly unlikely that the museum curator will receive such a large continuous dose of ingested mercury, but this extreme biological example is useful to demonstrate the severe effects of mercury poisoning.

Poisoning can occur through all three pathways; inhalation of vapour, ingestion of small particulates, and absorption through the skin (Christie & Brathwaite, 1995). Vapour is the most hazardous; liquid mercury is partially absorbed through skin contact, as the physical properties of mercury do not aid absorption; ingestion in animals has been shown to absorb only 0.01% (Cotterell, *pers comm.*, 2011). A small dose will have extremely little effect on health, as the dose should be out of the body within 24 hours, but cumulative doses will result in severe health problems (Moseley & Redlands, 1909).

Mercury vapours are found naturally in the air, due to degassing from the Earth's crust, volcanic eruptions, and erosion from rocks, and mercury is present at small amounts of $0.5\mu\text{g L}^{-1}$ in groundwater (Bull, 2007). The 'recommended' long term exposure limit (8 hour average) is 0.025 milligrams per cubic metre of air (mg m^{-3}) (HSE, 2002a). This is the amount of mercury in the air, so for poorly ventilated store rooms, this measurement may be significant; but it obviously depends on how the specimens are stored and how frequently they are handled.

Concentrations of mercury vapour can increase as the temperature increases; 20°C equals approximately 13.2mg m^{-3} , and at 30°C the amount of vapour has more than doubled to approximately 29.5mg m^{-3} (HSE, 2002a). This example of increased mercury vapour is important to remember, but is only significant in small, poorly ventilated stores with large collections of mercury bearing minerals. The temperatures in the store rooms should be monitored and kept low and constant to reduce the amount of mercury vapour which could potentially evaporate. It is very unlikely that museums will hold large enough collections of mercury ores to pose any real risk, but again, it is useful for the curator to be aware.

Mercury and mercury ores need to be stored appropriately to minimise any potential risk. If in sealed boxes, the vapour from the cinnabar specimens can seep and once the lid is removed, a concentrated gust of vapour is produced (Buttler, 2008, *pers comm.*). Liquid mercury samples in collections are usually held in sealed glass vials to avoid evaporation. If there is a strong reason to open the glass vials, gloves and a face mask should always be worn, and the vials should be opened in a fume cupboard.

Interestingly, mercury has a very low freezing point (-39°C), so in theory, specimens could be stored in deep freeze. However, the author is unaware of any institution that stores specimens in this way, and this storage method seems impractical and expensive with new hazards created, such as frostbite. The most practical method for storing mercury and mercury ores is in clear polystyrene boxes, with no lid; lipped boxes will hold any liquid mercury that has seeped from the ore, and the lidless container allows mercury vapour to dissipate and not build up. 'Toxic' labels should be clearly displayed on the outside of the boxes and storage drawers holding any mercury related specimen.

Toxic elements: Lead

Lead bearing ores and minerals, such as galena, anglesite, mimetite, and pyromorphite are not considered as potentially hazardous as the other examples such as lead oxides (litharge and minium) and lead chromate (crocoite), because they are not easily absorbed in the body. Some lead minerals, such as cerussite and pyromorphite sometimes have naturally fine crystal growth, and are very friable, but due to their high density are unlikely to become airborne. However, cerussite (lead carbonate) has the potential to be absorbed by stomach acid so particulates from this mineral could have the potential to cause harm. The sulphide galena, although a lead mineral, is not considered toxic because it is insoluble (Lambert, 1994a).

Along with mercury and arsenic, lead minerals have been used in China as medicines for over 2000 years (Weidong Yu, *et al*, 1995). Lead oxides have been used for treating skin diseases, epilepsy and depression (Weidong Yu, *et al*, 1995), and because the patients are recommended to take the drug for prolonged periods of time, the effects are cumulative and can result in lead poisoning. An astonishing mineral drug in China, called the 'longevity gold pellet' was thought to increase lifespan and slow the ageing process; ironically it was made with mercury and lead, and people taking this immortality pill soon discovered their own mortality (Weidong Yu, *et al*, 1995). Lead ores are smelted today and used in paint, as alloys with other metals, batteries, ceramics and glass (HSE, 2009).

Lead can enter the body through ingestion or inhalation (HSE, 2009). The more toxic compounds are the synthetic ones; historically lead acetate (known as sugar of lead) was produced by treating lead oxide with acetic acid, and was added to wine to sweeten the taste. The body naturally removes lead, just as it removes other toxins that enter, which is why continuous doses will cause problems; our body is unable to remove more toxin than is being put in. Lead poisoning can result in headaches, tiredness, stomach pains, constipation and anaemia, kidney damage, and seriously affect male fertility (HSE, 1998).

Industrial workplaces where lead is mined and smelted have their employees regularly tested to assess lead levels in their blood. The exposure limit for general employees which will cause the company to take action and prevent lead levels increasing is 50 micrograms of lead per decilitre of blood ($\mu\text{g/dL}$), and for women capable of having children is $25\mu\text{g/dL}$ (HSE, 2009). The exposure limit of lead in the air is 0.15mg m^{-3} (HSE, 2002b). Employees working in industry, for example the scrap industry, batteries and alloys and re-

fining, are at much greater risk from increased levels of lead in their blood stream (HSE, 2010). This is because the processes they are working with daily produce large amounts of extremely fine airborne dust in their work environment. In comparison, curators are unlikely to work with a mineral specimen containing lead for each minute of an eight hour day for 5 days. Museum curators are not working with lead or processed lead at the same level of workers in industry, so already the risk is drastically reduced. The density of lead means that inhalation in the museum workplace is very unlikely.

Potential exposure should be prevented as much as is reasonably practical (HSE, 1998). Disposable gloves should be worn when handling specimens (HSE, 2002b), and disposed off to prevent ingestion of lead particulates. Directly after handling specimens, hands should be washed (HSE, 2009). It is important that other members of staff, researchers, and volunteers are aware of the safe handling methods carried out.

Cerussite and other potentially friable, soluble specimens which pose a direct hazard should be stored securely in clear lidded boxes, as described with the arsenic mineral specimens above. Clear boxes allow the specimen to be viewed without directly handling the specimen and the associated labels can be placed in the box facing outwards so they can be read without disturbing the specimen. The box should be lined with *Plastazote* to minimise any potential abrasion of the specimen against the box. A 'toxic' sticker can be attached to the outside of the box to warn other members of staff and future members of staff. The same storage can be used for galena, which will prevent abrasion of the specimen, but this mineral does not need a 'toxic' sticker on the box.

Toxic elements: Antimony

Antimony is rarely found in its elemental form; it is more commonly found in the ore stibnite (antimony sulphide) (Butteman & Carlin, 2004). Antimony occurs within other minerals, such as jamesonite, tetrahedrite, stibiconite, kermesite and senarmonite (Christie & Brathwaite, 1992), and is frequently associated with the elements iron, copper, lead, and silver (Butteman & Carlin, 2004).

Antimony is a soft, yet brittle, semi-metal. It has been used extensively in the past for everyday uses, including for mirrors and bells, and, fascinatingly, it was ground down and the powder was used as eyeliner and eyebrow painting by the Ancient Egyptians 2000 years ago (Wang, 1919; Christie & Brathwaite, 1992; Butteman & Carlin, 2004). It is currently used for flame retardants, batteries, glass, pigments, plastics, ceramics, and has been used as an alloy to add strength to other metals (Christie & Brathwaite, 1992; Butteman & Carlin, 2004). Some paints have been developed using antimony to make the paint water resistance (Wang, 1919).

Due to its commonly brittle form, antimony and stibnite may enter the body through inhalation and ingestion. However, with their large fragments, and high density antimony will not easily become airborne in the museum workplace. This is more likely for secondary antimony oxides which are more powdery resulting in potential airborne dust. Antimony can cause irritation to the eyes and lungs, and if inhaled in cumulative doses over prolonged periods of time, it may lead to acute health problems, in particular on the lungs, heart and stomach (U.S. Department of Health & Human Services, 1988; Butteman & Carlin, 2004). It may also be absorbed through the skin and the eyes (U.S. Department of Health & Human Services, 1988). Antimony toxicity has been investigated in urine from fire fighters wearing antimony trioxide as a flame-retardant in their uniforms, and there were no significant increased amounts of antimony measured (de Perio, *et al.*, 2010).

The Health & Safety Executive (2005) have recommended the workplace long term (8hrs) exposure limit of antimony in the air is $0.5\text{mg}\cdot\text{m}^{-3}$, so working directly with specimens in a fume cupboard will reduce airborne particulates. It is unlikely that the handling of specimens will produce such large quantities of airborne dust, as these exposure limits have been generally set for industrial workplace environments, but the curator should be aware and the reduction of exposure to antimony is still advisable.

When handling specimens containing antimony-bearing minerals, gloves should be worn (U.S. Department of Health & Human Services, 1988). The gloves can be disposed of, and hands should be washed, as this will reduce the risk of any particulates on the hands entering the mouth after handling the specimens. Not all specimens will be friable, but when developing repacking projects, imaging projects, or research on specimens, all work should be carried out in a fume cupboard. Staff should wear dust masks and eye goggles (U.S. Department of Health & Human Services, 1988), to reduce the risk of inhalation and ingestion. Specimens should be packed in the same method as the arsenic and lead examples above.

Summary

The general handling and storage for toxic specimens is the same whether dealing with the discussed elements, or barium, bismuth, boron, copper, fluorine, oxalates, selenium, thallium, and zinc; disposable gloves should always be worn, and hands should be washed immediately after handling (Lambert, 1994a). Disposable gloves will reduce any absorption of toxins through the skin, and it will also reduce the risk of ingestion, as any loose particulates will be disposed of with the gloves. Disposable lab coats can reduce the risk of particulates being transported from one location to another. It is important not to eat in the store rooms or around the specimens (Lambert, 1994a), as this will reduce any risk of ingestion further. Any work carried out on specimens, including storing them in new boxes, should be carried out in a fume cupboard. Goggles, dust mask and disposable apron should be worn to reduce the risk to the member of staff carrying out the work. The lab space can be cleaned down with a damp cloth, which can be disposed of.

Specimens are best stored in clear polystyrene boxes (Knell & Taylor, 1989) which should be clearly labelled as 'toxic' (Buttler, 1994; Lambert, 1994a), and because they are clear, it is easy to see the specimen without directly handling the specimen. Labels may be damaged with specimens in card trays; storing minerals in new boxes, labels can be placed in polyester sleeves and placed facing outwards in the box, so they are clearly visible without disturbing the specimen. There is a potential to have a 'toxic rating system'. A similar system was carried out with the radioactive minerals specimens held at PCMAG and green, orange and red stickers have been placed on the polystyrene boxes of the specimens; green for 'low radioactivity' specimens (0-10 $\mu\text{Sv h}$), orange for 'medium radioactivity' specimens (10-99 $\mu\text{Sv h}$) and red for 'high radioactivity' specimens (>99 $\mu\text{Sv h}$) Education staff may take specimens from the collections for school talks or activities so labelling the drawers and boxes will limit the mis-use of specimens from more inexperienced members of staff.

Specimens may move against one another during movement or handling causes abrasion and fine particles (Buttler, 1994). Ideally all mineral specimens should be packed with *Plastazote* cut-outs to secure the specimen and minimise further breakage and dust production (Lambert, 1994a). *Plastazote* is an inert material and will have no reaction with the specimen (Child, 1994). However, *Plastazote* is expensive, so good practice would be to break the main collection into smaller manageable collections (for example, packing the toxic mineral specimens first). If *Plastazote* is not available, acid free tissue can be used to create a nest and secure the mineral specimen in the box (Buttler, 1994).

It is important that other members of staff, researchers, and volunteers are aware of the safe handling methods carried out. All the database records of any toxic specimen should be updated on the museum database, including; image of the specimen; updated storage information; a note with the record to say 'hazardous specimen'. Moving specimens into new and suitable storage containers, provides the perfect opportunity to image the specimens. This updated information is vital to inform other members of staff, and future members of staff, the potential hazard this specimen presents (Freedman, 2011).

Some minerals automatically have a worry attached to them, which can lead to staff being over cautious. Recently, an emergency room in Denver was closed as a man was carrying a radioactive rock (which was shown to have 'low, low radioactivity') (Denver News, 2010). Most minerals in collections are safe, and a misunderstanding of specimens will prohibit the potential research. To prevent harm working with any collection, the correct identification of specimens is vital and the best way is to understand the specimens we care for, or if unsure, to seek advice from colleagues.

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Further information:

Support and advice can be found at;
www.geocurator.org
www.natsca.info

General information about minerals can be found on;
www.mindat.org

Information about the health and safety of asbestos can be found on;
<http://www.nsc.org/ehc/chemical/asbestos.htm>
<http://www.netregs.gov.uk/netregs/>
<http://www.hse.gov.uk/asbestos/index.htm>

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