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Identifying and managing radioactive geological specimens

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Abstract

Certain minerals, particularly those containing uranium [U] and thorium [Th], emit natural ionising radiation that presents a hazard to humans. Not all are easily identified, and the problem is compounded when radioactive elements substitute into minerals that are not normally radioactive, or form an unrecognised constituent of a specimen, whether mineral, rock or fossil. The extent of radioactive holdings in a collection can only be established by measuring ionising radiation emissions for all the geological specimens using appropriate detectors. Radioactivity is subject to a variety of legislation. The Ionising Radiation Regulations (1999) detail the requirements for the protection of persons exposed as a result of work with radioactive materials. However, geological specimens fall completely out of scope of the 2010 Environment Permitting (England and Wales) Regulations and the Radioactive Substances Act 1993 in Scotland and Northern Ireland. The Euratom Safeguards Treaty has placed additional responsibilities on some institutions. This paper summarises how to identify radioactive specimens, establish who is at risk, and set up local rules that keep risk as low as is reasonably practicable. It includes examples of different approaches taken in the authors' institutions.

Keywords: Radioactive; Ionising Radiation; IRR99; Radioactive Substances Act 1993; Environmental Permitting 2010; Health and Safety

Introduction

Radioactive specimens are present in most museum geological collections, and are a potential health hazard. There is no definitive guide to their identification and management, although Lambert (1994) and Freedman (2011, 2012) give useful case studies of approaches taken in the National Museum of Wales and Plymouth City Museum and Art Gallery, respectively. The authors of this paper identify radioactive specimens and evaluate the risk they pose in broadly the same ways, but each of their institutions has independently established different rules and procedures that provide good practice and suit local circumstances. These case studies demonstrate that there is no single best method for the storage of radioactive specimens, it will depend on the size and nature of the collection, and the resources available.

Any institution which has radioactive specimens will need to obtain professional advice on radiation protection and radioactive substances legislation. Specifically, where advice is sought on the actions necessary to comply with the Ionising Radiations Regulations 1999, this advice must be obtained from a suitable (and certificated) radiation protection adviser. Details of certificated radiation protection advisers can be obtained from the Society for Radiological Protection (www.srp-uk.org/contact). Institutions may choose to seek advice directly from the relevant regulator; in this case the Health and Safety Executive.

Our paper presented at the NatSCA conference on Policy and Practice in 2013 gives just a brief overview of the subject and a more detailed study is in preparation.

Radioactivity in geological specimens

Radioactivity is a natural phenomenon, and cannot be completely avoided. Almost all Earth and planetary materials contain radioactive elements, as do all living things; for example, the element potassium, essential to every living cell, is itself weakly radioactive. Minerals are the building blocks of the inorganic natural world. They are naturally formed chemical elements and compounds, the composition of which will vary only between narrow limits. With the exception of native mercury, they are all solids, and most are crystalline materials. However radiation can break down the ordered arrangement of atoms, resulting in a disordered 'metamict' state, a feature of some radioactive minerals.

All rocks are made up of one or more minerals, and both minerals and rocks can be cut and polished to form gemstones. The fossilised remains of living organisms are also made of minerals. Consequently, radioactive specimens are found in mineral, rock, fossil, and gemstone collections.

Uranium and thorium are the most common radioactive elements in geological specimens. Their radioactive decay generates a range of radioactive daughter elements, including radon, and a radon isotope known as thoron, which being gases, can escape from mineral grains and be breathed in. Radioactive geological specimens emit:

- **alpha radiation** – positively charged particles that have a range of a very few centimetres at most in air. They are not an external health hazard, but internal exposure can be very hazardous.
- **beta radiation** – negatively charged particles that range tens of centimetres. They are particularly hazardous to the eyes and skin.
- **gamma radiation** – electromagnetic radiation. The most penetrating kind of radiation, it is hazardous to all organs of the body.

All three kinds of radiation are hazardous if radioactive materials are ingested or inhaled.

Legal issues

In the UK, the Ionising Radiation Regulations (1999), concerned with the protection of human health, are enforced by the Health and Safety Executive, and must be complied with. The regulations aim to ensure exposures are as low as reasonably practicable 'ALARP' (i.e. as low as can be reasonably achieved, allowing for work related factors to be taken into account). These regulations lay down maximum levels of exposure for different classes of person and for different parts of the body, and they set maximum annual dose limits which must not be exceeded under any circum-

stances. Children and unborn infants are at particular risk, and so the maximum dose is set at a substantially lower level for under 18s and pregnant women.

It is a requirement of the Ionising Radiation Regulations 1999 that guidance on the application of the Regulations should be obtained from a suitable radiation protection adviser. This may be an individual; a member of a corporate institution; or in some cases, an institution's own in-house radiation protection officer may be a certificated radiation protection adviser. A suitable radiation protection adviser should be able to advise on all aspects of the Ionising Radiations Regulations 1999 that apply to work with geological specimens.

In Northern Ireland and Scotland, the law relating to the use and disposal of radioactive materials is the Radioactive Substances Act 1993, while in England and Wales, this Act has been replaced by the Environment Permitting (England and Wales) Regulations 2010. Importantly, in all parts of the UK, naturally-occurring radioactive materials (referred to as NORMs) in the form of geological specimens are out of scope of both the 1993 and 2010 statutes under most circumstances. Details are given in a 2011 document *Exemption Guidance - Radioactivity in museums* published online by the Environment Agency and by the Scottish Environment Protection Agency.

Some collections also need to comply with the Euratom Safeguards Treaty which has placed additional responsibilities for audit and management on institutions with inventories including uranium- and thorium-bearing minerals, monitoring their physical security. This sets particularly high standards of documentation and audit.

Managers of geological collections need to first identify which specimens are radioactive, establish who may come into contact with them, think how to minimise and monitor exposure, and then develop rules and procedures to minimise that exposure and ensure legal compliance.

Identifying which specimens are radioactive

Radioactive geological specimens fall into a number of groups. Firstly, there are minerals and rocks which contain uranium and thorium as essential constituents. The most common 'primary' minerals are uraninite (UO₂) (Fig. 1), often labelled as pitchblende; thorianite (ThO₂), and thorite (Th,U) SiO₄, which may be labelled orangite. These are all non-descript, black or brown in colour, rarely form good crystals, and are very hard to recognise by eye. However their high ratio of U/Th to other elements, means that they are the 'hottest' of the radioactive minerals.

'Secondary' minerals form by weathering and alteration of the primary minerals, and include carbonates, sulphates, phosphates, arsenates, vanadates and silicates which contain uranium or



Fig.1. typical non-descript uraninite from Cornwall; only the presence of yellow and green alteration products give a visual clue to its identity.
(photo: Oxford University Museum of Natural History)

um and other elements. These may be much easier to identify by eye. They are often brightly coloured apple-green, yellow or orange. They typically form coatings but can develop good crystals. Examples of the more common radioactive secondary minerals include;

- torbernite ($\text{Cu}^{2+}(\text{UO}_2)_2(\text{PO}_4)_2 \cdot 8-12\text{H}_2\text{O}$);
- autunite ($\text{Ca}(\text{UO}_2)_2(\text{PO}_4)_2 \cdot 10-12\text{H}_2\text{O}$);
- carnotite ($\text{K}_2(\text{UO}_2)_2(\text{VO}_4)_2 \cdot 3\text{H}_2\text{O}$);
- uranophane $\text{Ca}(\text{UO}_2)_2[\text{HSiO}_4]_2 \cdot 5\text{H}_2\text{O}$.

Minerals containing rare earth elements (REEs) can have some of the REE substituted with thorium. This is not usually evident from the mineral's published chemical formula. Monazite ((Ce,La) PO_4) can form economically important beach sands, while allanite-(Y) ($\text{CaYFe}^{2+}\text{Al}_2(\text{Si}_2\text{O}_7)(\text{SiO}_4)\text{O}(\text{OH})$) is one of a number of REE minerals that typically occurs as dark-coloured crystalline masses in certain pegmatites, coarse-grained igneous rocks.

Lambert (1994) includes lists of names and synonyms of radioactive minerals, to which a small number of more recently discovered species may be added.

Radioactive minerals can be minor or significant constituents of many rocks, especially granites and granite pegmatites, and vanadium-bearing sandstones. They can also be present in fossil specimens. Radioactive fossils are not generally common, but may be abundant at some localities. The fossil itself may be radioactive, the surrounding rock matrix, or both. Phosphatic fossils can absorb uranium from groundwaters, and over time may become significantly radioactive. Well-known examples include some Devonian fossil fish from the north of Scotland, Jurassic fossils from the Morri-

son Formation of the USA, and Tertiary mammal bones from the Sivalik Range in Pakistan.

It is important to remember that mineral and rock specimens usually comprise a mixture of different minerals. U/Th minerals may not be the most important, and may not be listed on labels or in catalogues. Indeed they may not even be visible if surrounded by other minerals in the specimen. Consequently, radioactive minerals can occur ANYWHERE in a geological collection and it is usually advisable that an entire collection should be surveyed for radioactive specimens.

Artificial materials and artefacts found in geological and other collections can also be radioactive. They include, for example, gemstone models made from yellow uranium glass, radioactive paint used for making fluorescent dials in instruments, and 'Trinitite', a rock fused by the 1945 Trinity atomic bomb test. As these are not naturally occurring radioactive materials, advice on their legal status should be sought from a radiation protection expert.

The detection of radioactive geological specimens is easy using a suitable radiation monitor (for example, a sufficiently sensitive contamination monitor). These instruments are available in a range of different technical specifications, and expert advice should always be sought to ensure the correct equipment is purchased. Instruments may measure counts per second (cps), the number of pulses of radiation reaching the instrument's detector; or they measure microsieverts per hour ($\mu\text{Sv h}^{-1}$), a measure of the biological effect of radiation over an hourly period. This is the unit used in setting dose levels for compliance with the Ionising Radiation Regulations 1999. It is important that institutions holding radioactive specimens should have access to a dose rate meter or count rate meter to locate radioactive specimens, to make sure radiation levels are not exceeded for safe storage, and to detect contamination during routine work or in an emergency.

Identifying who is at risk

A management plan for radioactive geological specimen must cover all the people that could come into contact with them. These might include:

- Curatorial staff
- Interns and volunteers working on collections
- Cleaning and maintenance staff
- External contractors
- Research visitors
- Front of house staff
- Visiting public
- Emergency services

The number of people exposed to radioactive material should be kept to a minimum, and that might influence, for example, whether display of a radioactive specimen is *really* necessary.

Developing rules and procedures

Any institution holding radioactive geological specimens will need to establish rules and procedures to ensure it complies with the law and keeps risk as low as reasonably practicable. These 'local rules' should address:

- Who is in charge and has responsibility for compliance (the person designated Radiation Protection Supervisor).
- Where professional advice can be obtained;
- Who is permitted to handle or work with radioactive specimens, and whether they should be designated radiation workers.
- What training they should receive.
- What precautions must be taken when working with radioactive specimens.
- How incoming radioactive specimens are processed.
- How radioactive specimens are organised or segregated. It may be necessary to designate a 'Controlled area' or 'Supervised area' depending on radiation levels.
- Where radioactive specimens are kept, how they are stored and documented.
- Procedures for sampling, researching, loaning and disposing of specimens.
- How to deal with loss, theft, emergencies and other incidents.

Local rules are normally prepared by the radiation protection adviser working closely with the relevant museum staff. It is important that everyone, including management staff, should be fully aware of and comply with the institution's 'local rules'.

Local rules should lay out procedures for dealing with unexpected incoming material, for example public enquiry specimens. Other areas that will need particular consideration are the provision of suitable specimens for student or public handling; any display of radioactive specimens, and the management of radioactive specimens if they are transported and used off-site.

Minimising exposure

There are four ways to minimise exposure to ionising radiation, summarised simply as CONTAINMENT, TIME, DISTANCE, and SHIELDING.

Firstly, use of suitable **containment** to ensure that radioactive materials are segregated to ensure exposure is restricted and, in the case of crumbly or powdery specimens, that any contamination arising from specimen damage does not spread.

Secondly, by reducing the length of **time** a person is exposed to radiation. Specimen documentation, including images, can be used to help select which samples are to be used. Procedures should be planned carefully beforehand, ensuring all materials are ready to hand. Specimens should be returned to safe storage as soon as possible after use.

Thirdly, by increasing the **distance** between the person and the radioactive specimen (Fig. 2). The inverse square law applies as a very broad rule of thumb (it is accurate for a hypothetical point source), so double the distance between a person and a specimen to get just a quarter of the intensity of radiation; quadruple the distance, and the intensity reduces to just a sixteenth. In practice, this

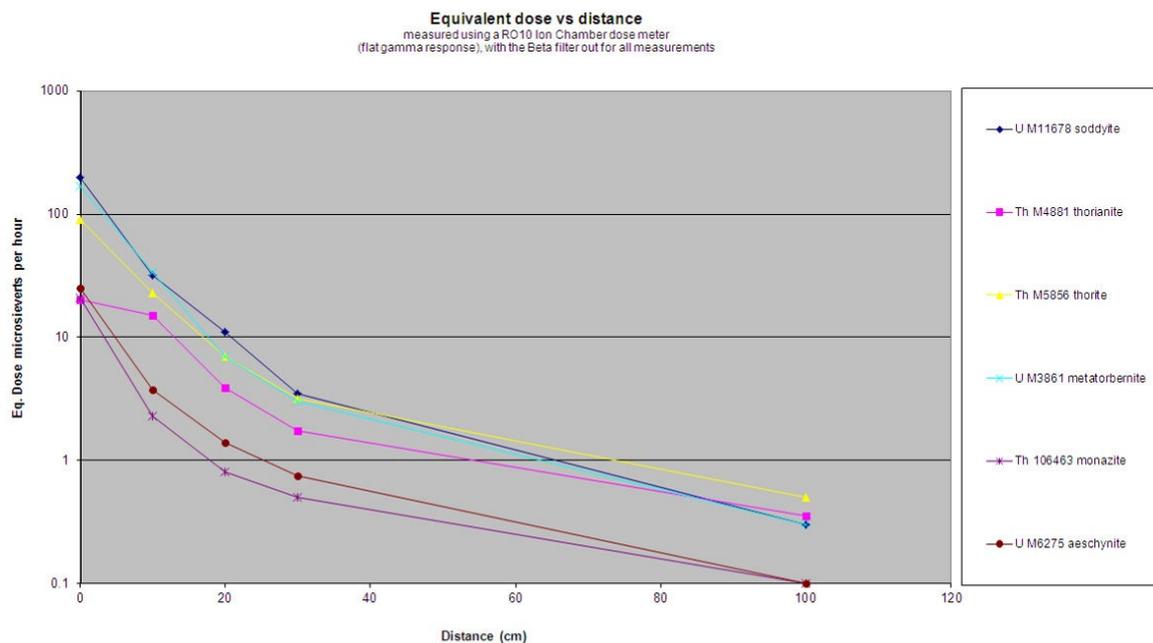


Fig.2. Measurements at the Hunterian for six different minerals show the rapid fall-off of radiation levels with distance. For example, a sample of metatorbernite, a uranium-bearing mineral that is relatively common in museum collections, gave a surface reading of $170 \mu\text{Sv h}^{-1}$. The reading dropped to a low safe level of $0.3 \mu\text{Sv h}^{-1}$ just a metre away. (source: The Hunterian, Glasgow)



Fig.3. Distance can be increased by picking up a specimen's card tray rather than the specimen itself. (photo: Simon Haycox, University of Oxford)

means that simply stepping back from a specimen will reduce exposure significantly. Other simple strategies can help; Keeping labels clearly visible will reduce the need to handle a specimen. When handling is necessary, the specimen's card tray or box can be picked up, rather than specimen itself (Fig. 3).

Finally, using **shielding** to protect workers from radiation emissions. Laboratory coats and disposable gloves should always be worn to reduce risk of contamination to skin and clothes. A beta radiation shield, made of thick transparent acrylic, used when working on a specimen, will help protect the body from beta radiation.

Uranium and thorium bearing minerals generate gaseous decay products: radon and thoron. Collections of minerals can potentially generate significant quantities of radon gas that could present a radiation risk on inhalation. Radon gas should be fully dissipated in a well-ventilated area and therefore storage arrangements should facilitate this.

As with all handling of unknown or potentially toxic minerals or materials, users should not eat, drink, bite nails, or apply make-up while working with radioactive specimens. This will reduce the risk of ingesting radioactive material. The advice of a radiation protection specialist should always be sought before embarking on work with finely particulate specimens, or any procedure that might generate radioactive powders or dust. Such work will normally require a Scheme of Work to be prepared in advance.

Monitoring exposure

Monitoring of exposure to radiation takes two forms; firstly personal monitoring, and secondly environmental monitoring. It is important to obtain and advice and training from a professional radiation protection adviser to ensure that the correct equipment is chosen and that it is used properly.

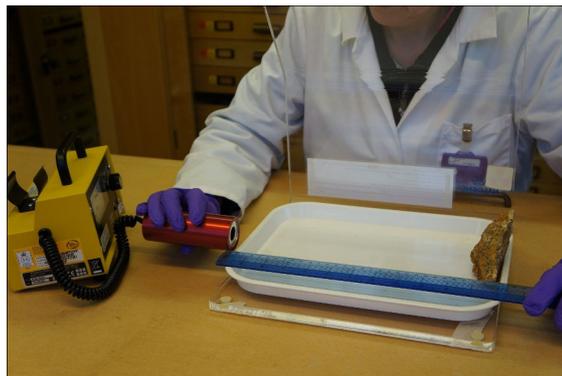


Fig.4. Measuring radiation levels at the Oxford University Museum of Natural History. Note the use of protective clothing and a beta-shield. (photo: Simon Haycox, University of Oxford)

There are a number of ways to monitor personal exposure to radiation. Personal dosimeters (known as TLDs - thermoluminescent dosimeters) are worn as badges. The dosimeter is returned to the issuing authority for assessment at regular intervals, not exceeding 3 months, and any recorded exposures above background levels are notified to the wearer. It is important that the badge is kept well away from radiation sources when it is not being worn. Similarly, finger-tip TLDs may be worn under disposable gloves where extremity exposures may be significant during specimen handling.

Both of these methods may only indicate high level of exposure some time after an incident. However, vigilant use of a dose rate meter or count rate meter of the kind used to detect radioactive specimens in a collection provides a continuous indication of an individual's potential radiation exposure. Contamination monitors allow an **immediate** check for contamination to the skin and hair, and should be used routinely to check for personal contamination during and after working with radioactive specimens.

Both radon gas and radiation levels require environmental monitoring. Radon levels are normally monitored using radon detectors hung in stores and workrooms. These devices can be obtained from Government agencies or radiation protection companies, and should be returned to them for results after a period of 3 months. If the results are higher than the recommended levels for the workplace, additional ventilation will be needed.

Radiation levels should be measured at storage surfaces to ensure that radiation levels are safe for those working in those areas. This is carried out with a dose rate meter. Again distance is important and moving specimens to the back of a storage drawer, or spacing them out more to reduce the density, may be sufficient to keep radiation levels safe for workers in front of the cabinet. Levels of radiation will increase if radioactive specimens are brought together in one place, conversely they can

be reduced by dispersing radioactive specimens through the collection. Radiation levels should be checked whenever specimens are moved, to ensure compliance with local rules and the law.

Additional monitoring will be needed when working with radioactive specimens, and extra care will be needed to minimise contamination from crumbly or powdery specimens. All work should be carried out in an easily cleaned plastic tray. Contamination can be detected and measured using a count meter of the kind used for locating radioactive specimens in the collection. Surfaces and trays should be cleaned with damp wiping tissue, and then re-checked and re-cleaned as necessary until all contamination has been removed.

Managing specimens

Some local rules can be complied with by good general museum practice. Managing radioactive specimens requires up-to-date acquisition and disposal policies, good levels of specimen documentation, and high standards of security to control access to specimens and audit specimen movements. It requires preventative conservation measures, for example to protect specimens from abrasion and poor handling. It also requires attention to health and safety policies to protect people in collections areas, remembering that minerals can be toxic or asbestiform as well. Radioactivity (along with other hazards) should be specifically recorded on any Collection Impact Form and evaluation prior to acquisition of a specimen.

Details of radioactivity (radiation monitor reading, and the distance from a specimen at which it is taken) should be an integral part of the museum's specimen documentation, as should images. Specimens should be individually photographed because referring to an image can help reduce the need to spend time in close range of the specimen as well as providing a useful record for security purposes (Fig. 5).

Signage and labelling are important. Specimens can be individually tagged with a small radioactive warning sticker, but in general, clearly visible warning labels using the internationally agreed radiation warning symbol should accompany every radioactive specimen in storage. Cabinets containing radioactive specimens should also be labelled, as should any storage areas or rooms set aside for the storage of radioactive material (Fig. 6). However, special consideration should be given if the doorway leads off a public area, not only to prevent unnecessary alarm, but also to avoid compromising security (Fig. 7).

Different approaches to storage

Our experiences show that it is possible to comply with the law and manage radioactive specimens effectively, using very different procedures.

The National Museum of Wales segregates all specimens with surface readings above back-



Fig. 5. Use of photographic records minimises time spent in a radiation store. This annotated photograph of uranium secondary minerals is sufficient to show what each specimen looks like, and where it is located in the box. (photo: Oxford University Museum of Natural History)



Fig 6. 'Low level' radioactive minerals at Oxford, for which both drawers and individual specimens have yellow radioactive warning labels. (photo: Oxford University Museum of Natural History)

ground levels (14 cps). This comprises nearly 700 specimens. These specimens are stored in a locked 'controlled area' with very restricted access. All specimens are sealed in containers and dispersed around the controlled store with just a few specimens per drawer. The store has a strong air extraction system so containers can be safely opened in the store. Specimens can be used for student/public handling if the container surface dose rate is below 7.5 μ Svh-1.

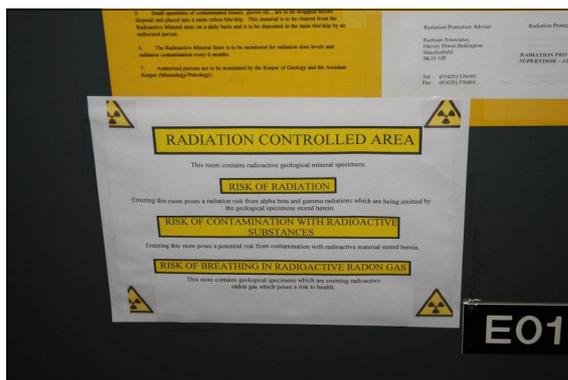


Fig.7. Radiation stores must be secure, with restricted access, and appropriate warning signs. (photo: National Museum of Wales)



Fig. 8. Radioactive specimens are stored in desiccating cabinets at the Hunterian. These must only be opened in the open air. (photo: The Hunterian, Glasgow)

The Oxford University Museum of Natural History measures radiation levels at 30cm from the specimen surface, a typical 'working distance'. It divides radioactive specimens into two groups, those above background but less than $2.5\mu\text{Sv h}^{-1}$ at 30cm are designated 'low level radioactive', and those above $2.5\mu\text{Sv h}^{-1}$ at 30cm are designated 'high level radioactive'. 'Low level radioactives' comprise about 750 specimens and are dispersed in the main stores so that measurements at the surface of any cabinet must never exceed $2.5\mu\text{Sv h}^{-1}$. A radioactive warning label is clearly displayed with each specimen and handling restrictions are enforced. 'High level radioactives' comprise around 150 specimens, approximately 0.5% of the mineral collection. They are stored in a secure 'controlled area' which has very good natural room ventilation to dissipate radon gas. Only designated radiation workers are permitted to handle these specimens.

The Hunterian, University of Glasgow, also has a two tier system. 'Radioactive specimens' are those which measure between 1 and $7.5\mu\text{Sv h}^{-1}$ at the surface (Fig. 8). These are dispersed in the store, with similar storage and management as the Oxford collection. 'Significantly radioactive specimens' measure greater than $7.5\mu\text{Sv h}^{-1}$ at the surface, and comprise just a small number of specimens. They are stored in secure 'Controlled Store', in desiccating cabinets to contain the radon, that must be opened in a fume cupboard or in the open air. Handling of these specimens is by designated radiation workers only.

Keeping the hazards in perspective

Just how hazardous is it to work with radioactive geological specimens? We can compare dose rates with those considered under the law to be safe for the adult, non-pregnant, general public. The current dose limit for the general public is 1 mSv per year. A person would have to be exposed to a specimen of $1\mu\text{Sv h}^{-1}$ for greater than 1000 hours or a $7.5\mu\text{Sv h}^{-1}$ specimen for more than 133 hours, to obtain their maximum yearly dose.

During the curation and isolation of around 75 'significantly radioactive' specimens in the Hunterian, a finger-tip monitor, worn over the work period of about a week indicated no significant excess exposure. Even during this relatively intense work with radioactive specimens, actual physical handling contact was only a few seconds to tens of seconds each, and hence cumulative exposure time was very small. When not actually handling specimens, the exposure a metre or two away was negligible.

The natural radioactivity in geological specimens rarely reaches levels where specimens cannot be used for a variety of educational and research purposes provided they are handled and stored correctly and responsibly. Plenty of help and advice is available from professional radiation protection advisers and from the Health and Safety Executive.

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References

- Lambert, M.P. 1994. Ionising radiation associated with the mineral collection of the National Museum of Wales. *Collection Forum*. Vol. 10(2) pp.65-80.
- Freedman, J. 2011. Storage of the radioactive mineral collections held at Plymouth City Museum and Art Gallery, UK. *Collections: A Journal for Museum and Archives Professionals*. vol. 7(2) pp.201-212.
- Freedman, J. 2012. Safe handling and storage of potentially hazardous minerals in natural history collections. *NatSCA News*. Issue 22. pp.51-65
- Northern Ireland Environment Agency, Scottish Environment Protection Agency and the Environment Agency 2011. *Exemption Guidance - Radioactivity in museums Version 1, September 2011*. <https://publications.environment-agency.gov.uk/skeleton/publications/ViewPublication.aspx?id=5c1db827-619f-420d-a6dd-1c83fc2d9c36> (also available on the SEPA website). (viewed 24 June 2013)
- Legislation.gov.uk 1999. *The Ionising Radiation Regulations 1999 no.3232* <http://www.legislation.gov.uk/uksi/1999/3232/contents/made> (viewed 24 June 2013)