

# Here be Dragons

- Or -

## The Care and Feeding of Radioactive Mineral Species

Being an introduction to radiological safety  
for the amateur mineralogist

**Radiological Protection**

By  
Alysson Rowan



**Version 1.86.01.0018**

**February 2017**

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First Published Electronically October 2008

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### Acknowledgements

They are far too numerous to mention individually, but my thanks go to the many people who have assisted by publishing reference data on the Internet, without whose help much of this manual would not have been possible.

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### Document History:

V 1.00.00.0077, 24 Oct 2008. First web release for peer-review.  
V 1.15.00.0093, 28 Oct 2008. Some expansion and correction.  
V 1.41.42.0117, 09 Nov 2008. Major revision into 2 sections.  
V 1.73.20.0164, 23 Nov 2008. Addition of Field Information.  
V 1.77.24.0169, 25 Nov 2008. Minor corrections to text.  
V 1.78.05.0171, 28 Nov 2008. Additions to FAQ.  
V 1.81.65.0198, 13 Dec 2008. Rearrangement of sections.  
V 1.84.39.0245, 17 Dec 2008. Minor corrections to new text and format.  
V 1.85.07.0265, 01 Jan 2009. Additional text and notes, minor corrections.  
V 1.86.01.0267, 22 Aug 2010. Minor corrections, changes to part IV  
V 1.87.01.0016, 18 Feb 2017. Minor corrections to content, serial number restart.

### Document Status

This handbook is a work in progress.

#### As of Version 1.81.65:

Parts I ó III are now complete,

Part IV text is complete subject to final checking. Mineral properties are under construction

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## About the Author

Alysson Rowan is a lecturer in Electrical Installation at North Devon College, a former computer engineer (the sort with spare components and a soldering iron) and is qualified in radiation safety and has spent a long time clearing up chemical and nuclear spills. She is also a life-long collector of minerals, and was once trained as a geologist.

She builds her own instrumentation and partly because it is cheaper that way, but mainly because she can.

## Acknowledgements

Many thanks for the numerous individuals on Mindat (<http://www.mindat.org>) for their comments, advice and assistance in preparing this handbook.

My thanks to Knut Eldjarn for his comments and assistance and in particular for reminding me of a simple method of displaying highly active specimens without being in the barely-shielded radiation field.

## Introduction

This is not intended to be a textbook for the advanced radiological worker; it is aimed at the complete scientific novice. Being a simple introduction, much of the science is grossly simplified, but it is intended to give a meaningful introduction to the amateur mineralogist and aims to help the amateur make reasoned decisions as to his/her safety requirements when working with naturally occurring radioactive materials.

The main intent has been to suggest measures and techniques that are achievable by the amateur in a domestic laboratory as opposed to a professionally equipped, dedicated radiochemical lab.

Many hobby activities involve a measured element of risk; the only way to remove that risk absolutely is to avoid the activity entirely. In order to remove the risk, you have to leave or limit your hobby, otherwise you have to enter into the realm of risk management.

At the end of the day, as an amateur, you have to make your own safety decisions based on what you feel is achievable and reasonable. This handbook aims to help you make those decisions. Ultimately, the safe option will always be *“If I cannot achieve a good minimum level of safety, I will not collect these specimens”*.

An awful lot of nuclear safety is about what you should not do around radioactive materials and I have kept to this convention as it is much easier to follow rules about what will do harm than to try and interpret rules about what won't.

The frequently asked questions are near the beginning of this manual. Please read them as there is useful information in there.

There is humour in the text. Don't be deceived, it doesn't make the point any less serious, it just means that I can't see any point in nuclear safety being boring.

### ***Introduction to the parts***

**Part I** is a quick-start guide to radiation safety for mineralogists and gemmologists.

**Part II** looks at the general principles of radiation safety. With regard to mineral specimens the likelihood of extreme radiation fields is relatively low; indeed, in one of the most active mines in Europe, South Terras Mine in Cornwall, the radiation fields are quite low. The main hazard at South Terras is the extremely high radon level deep in the mine giving rise to hazardous internal radiation exposure.

Further, consideration will be given to *specific activity* as a guide to anticipated dose-rate.

There is an element of mathematics involved that, whilst not terribly taxing, does require the use of a calculator with a broad numerical range. For this a cheap scientific calculator is ideal, standard pocket calculators with only basic functions tend not to have the accuracy in order to obtain meaningful results.

**Part III** is a short section on natural radioactivity and field collecting.

**Part IV** is a guide to specific mineral species and groups of minerals, and covers recommendations as to the general practices and handling of specimens of these species.

## ***Disclaimer***

This handbook is intended as a practical working guide to reasonable good-practice and a recipe-book of practical suggestions, not as an authoritative text. If you follow the guidelines set out here you should come to no harm from your radioactive specimens BUT  
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**There is only one way to avoid all harm from radioactive minerals, and that is to avoid them completely.**

The author, whilst open to constructive criticism and suggestions cannot be held responsible for your safety ó as a responsible adult, only **you** can take that responsibility.

## **Part I: A Quick Start Guide to Radiation Safety**

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## Introduction to Part I

This is a very quick and dirty introduction to Radiation Safety, and is intended for complete newcomers to the field. It is aimed at both new mineralogists and gemmologists and at the more experienced hobbyist who needs to know about *naturally occurring radioactive materials* (NORM).

There is an assumption that if a material is  $\pm$ natural, then it cannot do harm. This is patently untrue ó there are many toxic plants in the world, dangerous animals and lethal microbes. Many minerals are themselves toxic, but nuclear radiation seems to be forgotten. It is for this reason that this guide has been written.

Radiation can be a silent killer although, happily, rapidly lethal levels of nuclear radiation are rarely encountered in nature. Indeed, it is likely that we would not exist were it not for some levels of radioactivity in our environment.

## Quick Start Guide to Radiation Safety

### ***Where nuclear radiations come from***

Nuclear radiation, often termed *ionising radiation*, originates in the heart of unstable atoms, radioactive elements that were created in the process of the making of the solar system. These elements break down by emitting fast-moving particles and photons of light similar to X-Rays.

These unstable elements have become concentrated over the age of the Earth, and are found as pockets and lodes in a range of locations. Some commonplace minerals such as Zircon have tiny amounts of these elements incorporated into their structure, others are essentially radioactivity free.

#### ***To put this into perspective -***

Some commonplace elements possess some small radioactive characteristic ó Hydrogen, Carbon and Potassium, all essential constituents of life as we know it, are slightly radioactive. As a result **we** are slightly radioactive, and always have been.

Because nature abhors anything of absolute purity, there is inevitably a tiny quantity of (radioactive) uranium in even the purest drinking water, small amounts of radioactive radon gas in the freshest of air and traces of Thorium in your soil. All placed there by nature and not by mankind.

Even sunlight represents a radiation source ó the ultraviolet rays that give you a sun-tan (and possibly skin cancer) are kin to the gamma-rays from nuclear disintegration. In fact, there is gamma radiation emitted by our sun that we are inevitably exposed to for our whole lives.

- and all without ill effects.

### ***What nuclear radiations do to you***

Nuclear radiation, in short, causes damage to the cells of your body. This damage is largely to the structures of the cell but may involve the DNA in the cell nucleus. Usually the radiation will disrupt the cell sufficiently to kill the cell or it may cause some minor damage that is easily repaired. The latter is of no consequence at all; whilst the former is only significant when sufficient cells are being damaged to result in a radiation burn.

When the ionising radiation affects the cell's DNA, two outcomes are possible. The first is that the cell will die, either immediately or when it attempts to divide ó resulting in a similar situation as before. The second, and more serious consequence, is that the cell will continue to live and replicate as normal, but carrying with it a new genetic abnormality.

Under most circumstances, such abnormality results in the cell being treated as an intruder organism (infection) and is removed by the white blood cells. Exceptional circumstances will cause the cell to continue to thrive, and it may initiate the development of a tumorous growth, potentially a cancer.

The cells most sensitive to this type of damage are those undergoing rapid division: as part of the growth process in young people; as the normal process of repair of an injury of some kind; or as the normal operation of the lining of the gut or of the skin ó replacement of cells lost through normal abrasion.

### ***How to protect yourself from radiation***

There are two means of incurring radiation damage: radiations originating outside the body and radiations originating inside the body.

The second source of *radiation dose* is the more serious, as the radioactive material not only affects the lining of the gut most severely, but can become permanently lodged in the body, causing a concentrated radiation dose to that part of the body.

To prevent this, simple hygiene rules should be observed. Imagine, for the moment, that the radioactive material is a dangerous bacterial culture. How would you deal with it?

- Wash your hands after handling the material.
- Wear (thin) gloves wherever possible when handling the material.
- Do not handle the material alongside food, where food is prepared or where food is eaten.
- Do not lick, eat or sniff the material.
- Avoid causing dust when handling the material.
- Keep the material in a closed container (bag, box, cabinet etc.) whenever not in use.  
- and locked away, if possible.
- Keep material away from children and animals.

The first source of radiation dose, although less acutely hazardous, is the more difficult to minimise. In brief, the principles of *size*, *time*, *distance* and *shielding* are used. Minimising the time spent deep in the radiation field, keeping as far from the material as possible and putting something between you and the radiation source will all help reduce your received dose. Smaller samples give less radiation dose than an equivalent large specimen. In brief:

- Keep your specimens as small as you can (yes, this one hurts an enthusiast badly).
- Avoid handling the material more than is necessary.
- Use handling equipment (tongs, tweezers or even specimen mounts) whenever possible.
- Work at arms $\varnothing$ length if possible.
- Keep a layer of dense material (lead-backed plywood, lead-copolymer acrylic sheet, barium plaster or a thick sheet of steel) between your body/face and the material.
- Keep highly active, large or stock specimens in shielded storage (steel and wooden boxes are generally good enough for most specimens.)
- Don $\varnothing$  use a hand-lens when peering closely at your specimen  $\acute{o}$  use a simple binocular microscope, and maintain your distance that way.

Finally, most natural radioactive specimens give rise to radioactive Radon gas. Unless your radioactive specimens are large or very numerous, the ventilation in a typical house is sufficient to prevent excessive build-up of Radon. Remember to ventilate your specimen cabinet well before you get those specimens out  $\acute{o}$  a single lung-full of radon-enriched air is definitely to be avoided.

### ***Natural Radioactivity versus Artificial Radioactivity.***

There is no difference between the radiations encountered in nature and those encountered in the laboratory, with one exception: the radiation levels available in the laboratory are many times higher than anywhere in the Earth's crust today.

Processes that take many millions of years in nature can be reproduced in a few hours to weeks in a nuclear laboratory. For gemstone enthusiasts, this means that naturally radiation enhanced colour in gems may be re-created quickly and cheaply in the laboratory.

Unfortunately, this generally requires the use of a nuclear reactor where the neutron flux causes some atoms of the crystal to become themselves radioactive.

For the first few days to weeks, radiation enhanced stones should be treated as highly radioactive. After this time, the radioactivity will fall off to very close to nothing..

Unfortunately, some mineral impurities may become *activated* and as a consequence will undergo radioactive decay over a period of years to centuries ó rendering these minerals inappropriate for radiation enhancement, and dangerous for use.

Placing your favourite topaz next to a large piece of uraninite will eventually enhance the colour, but the colour change will be undetectable in your lifetime, or those of your descendants. Nor will your topaz become itself radioactive, although it may suffer surface contamination by radon daughter nuclides or by dust from the uraninite.

Parts of the process by which many stones become radiation-coloured is imperfectly understood as yet. As understanding of the mechanisms improves, more and more gemstones are able to be enhanced by radiation treatment.

### ***Special information for gem and cut-stone enthusiasts.***

There are many gem and decorative stones that are radioactive, only rarely are they sufficiently hot to represent a genuine hazard. The classic example is Zircon.

This having been said, there are a number of very attractive rare-earth minerals that are occasionally used for decorative purposes. These can be noticeably radioactive due to the substitution of Thorium for the rare-earth elements.

Similarly, it is not unusual for a particularly attractive or interesting specimen to be cleaned, polished and mounted for wear as jewellery. If the mineral is not one that you know, then it is worth checking it against the list of known radioactive minerals, or getting someone to check it with a Geiger counter. Uraninite has been known to be mounted as a pendant, as has thorium-rich columbite, both of these being particularly radioactive minerals.

It is worth considering whether a radiation enhanced gem will be well suited for your use. The enhanced colour of the stone *may* be less stable than in a natural stone, the colour changing over a period ranging from weeks to years. In some cases, inexpensive stones are not checked for residual radioactivity before shipping (the problem of activated impurities).

**Part II: *An introduction to the principles of radiation Safety Practice*****Arrangement of Part II**

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## Introduction to Part II

In Part II we will look at the general principles of radiation safety. With regard to mineral specimens the likelihood of extreme radiation fields is relatively low; indeed, in one of the most active mines in Europe, South Terras Mine in Cornwall, the radiation fields are quite low. The main hazard at South Terras is the extremely high radon level deep in the mine giving rise to hazardous internal radiation exposure.

Practical approaches to radiation safety will be discussed; this will include aspects of storage, handling, display and disposal. Whilst the extreme exposure conditions are discussed, the degree of protection must be modified for whatever is appropriate.

Consideration will be given to *specific activity* as a guide to anticipated dose-rate.

There is an element of mathematics involved that, whilst not terribly taxing, does require the use of a calculator with a broad numerical range. For this a cheap scientific calculator is ideal, standard pocket calculators with only basic functions tend not to have the accuracy in order to obtain meaningful estimates.

## Radiation Safety Principles

### *The Radiological Hazard*

Ever since 1945, we have had it drummed into us that nuclear radiation is dangerous. This is true, but we often become blinded by the radiological hazard, so that we fail to see it in perspective.

Generally speaking, when dealing with mineral specimens, the radiological hazard is far less than the toxic nature of the specimen, and may even pale into insignificance when a hand-specimen of Uraninite is used as a blunt instrument by an irate spouse.

You have no intrinsic way of detecting nuclear radiation without suitable scientific instrumentation. You cannot see it, feel it, smell it, taste it or hear it. The damage it does may not become apparent for thirty, forty or fifty years. You may not ever be aware that you have suffered damage from nuclear radiation at all.

The risks are, with care, small, but are significantly more significant for children and people who have suffered injury. The ultimate risk is the generation of radiation-mediated carcinomas. Just as prolonged exposure to strong sunlight can result in skin cancer, prolonged exposure to nuclear radiation can result in other cancers.

As a guide, it is usually stated that the risk of dying of radiation-related causes for radiation workers is equivalent to one return transatlantic flight at high altitude for each year of exposure. Or in terms of conventional risk-taking, crossing the road once. As a non-radiation worker, your risk is estimated to be one tenth of this level ó and our aim is to keep it there.

Because of the statistical nature of risk-taking, *theoretically speaking*, a single exposure to a radioactive specimen may trigger the DNA change that causes a cancer, or you could work with the material all of your life and never suffer any ill-effects. For most of us, the risk from the proximity of properly stored radioactive minerals will be negligible ó you are more likely to suffer injury from every other aspect of your environment.

## The Radiological Hazard FAQ

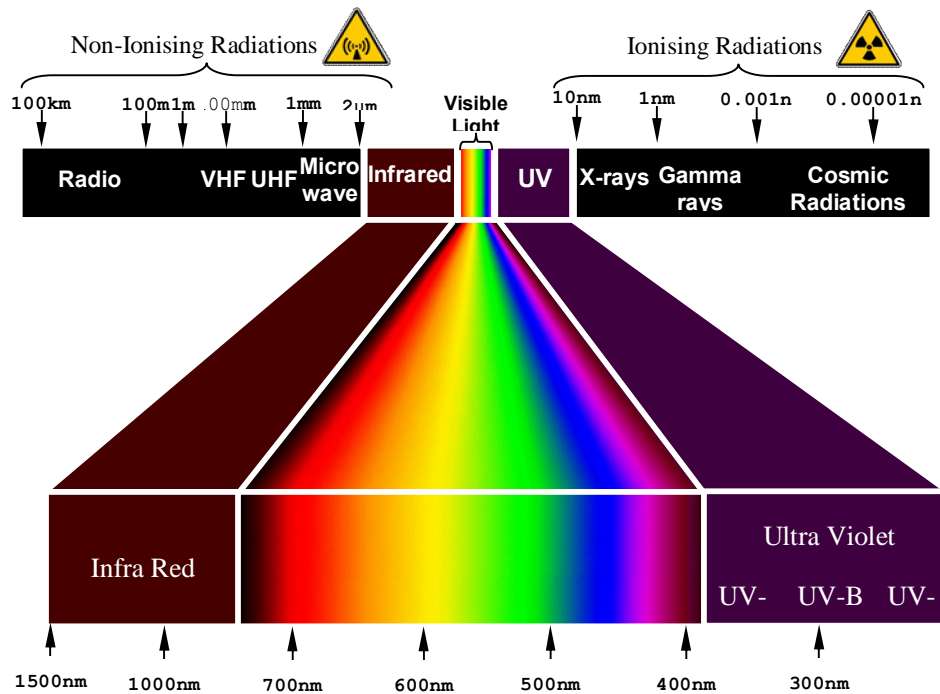
Frequently asked questions about radiation and radiation safety

### What is Electromagnetic Radiation?

The short answer is "Light". Visible light is only a small part of the entire spectrum of electromagnetic radiation. Radiation outside of the visible range tends to be less prevalent in nature, and more or less harmful to terrestrial life.

At wavelengths below about 350nm, electromagnetic radiation becomes increasingly able to penetrate matter and to displace electrons from their rest locations in the atoms and molecules of that matter. When electrons are ejected from the atom entirely, this creates ions, hence *ionising radiation*. These radiations are immediately damaging to us, causing cellular and genetic damage which can often lead to radiation burns and cancer.

At longer wavelengths longer than about 700nm, infra-red and microwaves warm us by causing an increase in the size of the vibrations of the atoms and molecules and may lead to severe burns. Further into the radio spectrum, the radiation interaction is mainly with the electrons of conductive materials, causing small electrical currents to flow and can produce diffuse lesions which resemble ionising radiation damage, with similar effects. Further still, the radiation can induce small electric currents in the body, interfering with nerve function.



At the most extreme ends of the spectrum, the radiation has little, if any effect on us passing through or around us without ever interacting with us. In the case of the so-called *cosmic radiations*, these photons rarely interact with anything, the most energetic having been discovered only since the 1990s.

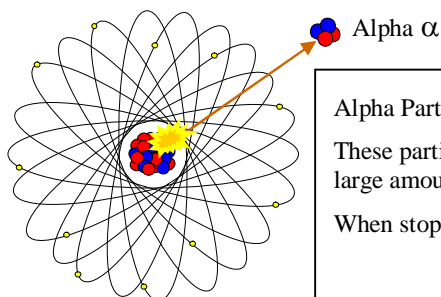
## What is Nuclear Radiation?

Briefly, Nuclear Radiation is *the emission of energetic sub-atomic particles and energetic photic quanta from a material caused by the disintegration of unstable (radioactive) nuclei.*

Errrrm í .. In English, that means: atoms of some substances are unstable, so they break up, releasing tiny bits of matter and pulses of light as they do so.

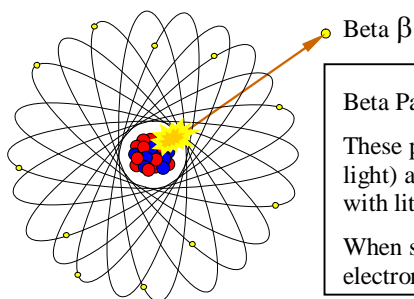
These particles (mostly Alpha and Beta particles) and light (Gamma radiation) are able to cause damage to some substances, most notably the cells of living organisms.

Alpha particles are big, slow and heavy ó being the same as helium atoms without their electrons. They do a lot of damage, but happily, are rendered safe by the thickness of a sheet of paper or a few inches of air ó or the thickness of your skin.



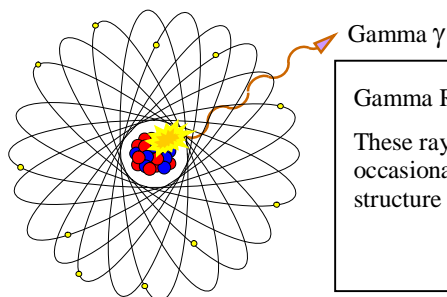
Alpha Particles comprise two neutrons and two protons.  
These particles move (relatively) slowly and will cause large amounts of ionisation and recoil damage.  
When stopped, these particles become Helium gas.

Beta particles are electrons. Tiny and moving at almost the speed of light, they penetrate the skin, a few millimetres of plastic, a couple of millimetres of aluminium or a sheet of lead foil. They do considerable damage, and will cause a burn (similar to a severe sunburn) if a beta emitter is left in contact with the skin for a period of time.



Beta Particles comprise a single electron.  
These particles move rapidly (about 90% of the speed of light) and will cause moderate amounts of ionisation but with little recoil damage.  
When stopped, these particles become part of the electronic structure of matter.

Gamma rays pass through most things without interacting. They are very similar to x-rays. Gamma radiation is partially shielded by a thick layer of lead, but they generally do much less damage than beta or alpha rays.



Gamma Rays comprise a short wavelength light photon.  
These rays rarely interact with matter, but will occasionally cause an electron to be displaced from the structure of the interacting atom.

There are other types of nuclear radiation, but these are so rarely encountered in naturally occurring conditions that they need not be considered.

### Origin of Nuclear Radiations

The atom is an object so small that the head of a pin contains about  $900 \times 10^{18}$  atoms (900 million million million atoms). Essentially its structure comprises a tiny nucleus which contains over 99% of its mass, surrounded by space which is sparsely occupied by orbiting electrons.

The nucleus is itself constructed of smaller particles, protons and neutrons. The number of protons determines what chemical element the atom is; the number of neutrons determines which *isotope* of that element it is ó that is to say, what sort of atom of that element it is.

Many elements have more than one stable isotope, but all have at least one unstable isotope, a form of that element that is prone to nuclear decay. A large excess or deficit of neutrons will lead to instability. Most unstable isotopes are artificial, but there are a number of natural ones.

Very large atoms are invariably unstable (the heaviest stable element is Lead).

When unstable atoms decay, they generally eject their excess energy as high velocity particles (*Alpha* and *Beta* particles) and as *quanta* (*Gamma* rays). Gamma rays always accompany some other form of decay. The element resulting from the radioactive decay may itself be radioactive, thus the sequence may result in a *Radioactive Decay Chain*.

Nuclear radiations when they interact with other atoms, will cause electrons to be ejected from those atoms (*ionisation*), and if sufficiently energetic they may also displace the atoms struck (*recoil damage*).

### **What is “Radiation Dose”?**

This is the amount of radiation you receive to your body, and may be considered to be equivalent to the amount of damage that it does to your living tissues.

Not all radiations are equivalent, and there is a way in which the equivalent dose may be calculated. This is technical stuff beyond the scope of this article, especially since we are discussing absolute minimum doses from small amounts of radioactive material.

### **What are Daughter Products?**

When radioactive elements undergo radioactive decay, they change into other elements (a process known as *Radioactive Transmutation*). In the case of the two naturally occurring radioactive elements we are mainly concerned with, Uranium and Thorium, these *daughter products* are themselves radioactive. In fact, they account for the vast majority of the radioactivity of the mineral.

The most popularly known members of these series are Radium (used for luminising clocks and watches for many years) and Radon, a chemically inert, radioactive gas that causes trouble in many homes and businesses in various parts of the world.

Ultimately, the final, non-radioactive, product of these *decay chains* is lead.

### **Are my mineral specimens legal?**

In *most* countries there is no legal way in which the obtaining and ownership of naturally occurring radioactive materials is prohibited, therefore your radioactive minerals will be legal. (Check your local ordinances.)

Most countries apply controls to the processing and refining of ores containing radioactive elements. Since we are discussing mineral specimens collected for personal, recreational and educational purposes, these laws are unlikely to apply.

## What are appropriate levels of protection?

The biggest question concerning collectors concerns what is an appropriate level of protection. To answer this question you must ask yourself the following questions:

- *How much radioactive material will I be collecting?*
- *How big will my specimens be?*
- *How much handling and preparation will my specimens require?*
- *Are there other considerations such as children or pets?*
- *Do I feel competent to risk a lower level of protection?*
- *How paranoid am I?*

Bearing these questions in mind while you read the following chapters will help you answer this question.

As a guide, though, for hand and cabinet collections ó

- A few specimens of *REE minerals* (q.v.) will require only considerate handling and a sheet of glass between you and your display.
- A few small specimens of uranium crusts will have approximately the same needs as the REE minerals above.
- A selection of radioactive fluorescent minerals such as Autunite will require consideration of the spread of autunite dust, and a sealed cabinet.
- A systematic collection of Uranium and Thorium minerals will require, possibly, lead shielding and shielded display cases.

And for Thumbnail and Micro collections -

- A systematic collection of uranium and thorium minerals will require, possibly, a lead-foil lined wooden box for storage, and should be examined only through a microscope or large diameter lens (i.e. not an eyeglass or miniature hand-lens).
- A few uranium or thorium micro specimens pose no significant radiation hazard unless you are handling them constantly, but will require a microscope rather than a small hand-lens for examination.

Preparation of specimens for display will require a higher level of sophistication than simply placing a specimen in a cabinet; Children and pets mean that specimens need to be secure in order to prevent unnecessary exposure.

Your level of paranoia is important. To be excessively cavalier is to invite an accident. On the other hand, excessive paranoia will paralyse your ability to make rational safety decisions. If your fear outweighs your rational decision-making capability, then you should simply part with any idea of collecting radioactive minerals.

Hopefully, reading this guide will help you to develop a healthy level of caution rather than a paranoid attitude toward your radioactive specimens.

## Will Nuclear Radiation cause me to turn into a mutant?

In a word, no. This is called science fiction. Whilst radiation causes mutations, in humans, mutations occur randomly much more often. The highest risk to health from exposure to nuclear radiations is the formation of cancers in the body.

The kind of radioactive sources we will discuss here are unlikely to give rise even to elevated risk of cancer, provided that certain precautions are taken. It is important to remember that radioactive materials are more dangerous to growing children than to adults (and most particularly to an unborn foetus), and are more dangerous to anyone when allowed into close proximity of rapidly dividing cells (such as close to an injury or in the human gut).

### **Will Nuclear Radiation make me sterile?**

Given a high enough radiation dose to the appropriate organs, yes, that would be a possibility. In reality, the kind of radiation dose that you receive from your mineral specimens is most unlikely ever to make a detectable difference.

### **Will Nuclear Radiation give me split ends?**

This is just silly. Split ends are caused by general health and diet. If you have split-ends caused by nuclear radiation, you are probably undergoing radiation therapy for cancer, and the radiation dose you get from your mineral collection is negligible compared with the dose you receive in the course of your medical treatment.

In fact the radiation dose you get from your mineral collection (unless you collect Uraninite by the kilogram) is likely to be negligible compared with the dose you receive in the course of a medical x-ray of a (suspected) broken bone.

### **Will I die of radiation poisoning if I eat my specimens?**

Probably not that you will, however, suffer the toxic effects of consuming the heavy-metal compounds (heavy-metal poisoning can be nasty at best and a lingering, agonising death at worst) and you will be at elevated risk of gastrointestinal and of bone cancer.

Remember that mineral specimens should be treated as poisonous unless otherwise stated, regardless of their radioactivity.

### **What is Radiation Sickness?**

This is a condition caused by exposure to extreme levels of nuclear radiation. The symptoms of a person undergoing radiotherapy for cancer are radiation sickness. Many chemical poisons produce a similar set of symptoms

It is probably impossible to develop radiation sickness from exposure to normally available radioactive mineral specimens for any length of time (unless you grind them to powder, inhale and/or eat them). Those symptoms you are suffering are most likely to be either food poisoning or stress, or if you have just got home from a collecting trip, it is quite likely to be heat-stroke and exhaustion.

### **What are the effects of Radiation on the body?**

Briefly, when nuclear radiation impinges on living tissues, the radiation damages (and usually kills) the cells it hits. There is a small chance that the damage (to the DNA) will result in a pre-cancerous cell which may eventually give rise to a cancerous tumour.

If enough cells are killed, then the result is a radiation burn. The most common of these is called an erythema ó a burn to the tissue below the skin, and resembling a very common form of radiation burn ó a sunburn (solar erythema).

When ingested or inhaled, the radioactive particles are in intimate contact with living cells (i.e. not separated from them by the thickness of the skin) ó and therefore the damage will be more severe, and more likely, especially in the case of the gut-wall, to result in a cancer being formed.

The low-levels of radiation exposure are more subtle, and may be indistinguishable from the normal process of living and ageing.

### **What are the effects of Ingestion of Radioactive Minerals?**

Different minerals exhibit different levels of toxicity. The degree of toxicity is also related to the amount of toxin absorbed.

Uranyl compounds  $[(\text{UO}_2)^{2+}]$  are typically most soluble, and affect the body more rapidly. Acute poisoning with Uranyl compounds results in acute renal failure due to necrosis of the renal tubules.

Long-term effects of exposure to Thorium and Uranous compounds as well as low-levels of Uranyl compounds will result in deposition of the heavy metal in the bones. This displaces calcium (weakening the bone structure) and irradiating the living bone tissue and surrounding structures. Typically, chronic exposure to low-levels of Uranium and Thorium will result in osteosarcoma (bone cancer), to leukaemia and related bone-marrow implicated cancers.

Chronic medium-level exposure can result in liver and renal damage.

Repeated exposure carries a high risk of cumulative effects.

Inhaled Uranous and Thorium compounds, and to a lesser extent the Uranyl compounds will result in both toxic and radiation damage to the lung. Long term effects will include bronchitic and emphysema-like symptoms as well as a range of pulmonary and pleural cancers.

There is little data available on the toxicity levels of the various compounds when encountered in non-working environments.

### **Will I be able to build an Atomic Bomb using my specimens?**

No. You require an awful lot of expertise and high-technology to refine the materials used to make an atomic bomb. Or a nuclear reactor. Or a radiotherapy system.

Besides, to do this, you would have to destroy your specimens, and that would be a terrible waste.

### **What is contamination?**

Radioactive Contamination is the presence of unwanted radioactive residue resulting from working with or the storing of radioactive material, in exactly the same way as you get chemical or biological contamination.

*Primary Contamination* is contamination that arises from direct contact with the radioactive material. *Secondary Contamination* is that arising from the transportation of contamination to another location (such as on your hands or feet).

Non-radioactive material cannot be made radioactive by exposure to ordinary nuclear radiations, but it can become contaminated through contact with loose radioactive material.

This process of *activation* requires a neutron source (usually a nuclear reactor), and takes place by a process similar to the reverse of nuclear decay. You literally stick extra neutrons into the nuclei of stable atoms.

### **What is the Inverse-Square law?**

This is a mathematical relationship that states that the radiation Dose-Rate from a radioactive source is proportional to one upon the square of the distance.

In simple terms, if you double the distance, you quarter the dose-rate.

Thus:

Relative Distance	Relative Dose rate
1	1
2	1/4
3	1/9
4	1/16
5	1/25

## ***Managing Radiation Exposure***

There are three factors which may be applied in order to reduce radiation dose:

- Time  
Reducing the time for which you are exposed will reduce the dose. No exposure equals no dose.
- Distance  
Increasing the distance from the source reduces the dose. Doubling the distance quarters the dose (the so-called *inverse-square law*).
- Shielding  
Placing layers of material between you and the radioactive source in order to absorb the radiation reduces the dose significantly ó especially in the case of Beta emitters.

These will be dealt with a little later when we discuss using your laboratory and storage of your specimens.

In addition, there are two other factors to be taken into consideration with radioactive minerals ó the risk of contamination and consequent ingestion/inhalation of the workplace residue, and the generation of Radon gas.

## **ALARP**

Throughout the process of considering radiological control, the underlying principle is ALARP ó As low As Reasonably Practicable. That is, all exposure to radiation and radioactive materials is to be minimised.

The best way to minimise exposure is, of course, to avoid all contact with radioactive material. This defeats the object of collecting radioactive minerals, so we must work within this restriction.

Under any circumstances, we must avoid any unnecessary radiation exposure to young people who are still growing, since they are more susceptible to radiation effects, and to the unborn foetus in the case of pregnant women. This may mean removing specimens from the dwelling, albeit temporarily, or placing them in a secure and adequately shielded place of storage.

## **Contaminated residues**

Wherever radioactive material is being worked, then residues remain. In a dedicated radiochemical laboratory, disposable coverings and washable, sealed surfaces are the norm. In the private lab, you can limit the spread of these residues by working in a similar manner.

Remember that although the amounts of radioactive material are tiny, and usually may be safely (and legally) disposed of through the domestic refuse collection, it is good practice to ensure that these materials are securely sealed in preparation for disposal. This is discussed later.

**Radon Gas and its daughter products.**

The radioactive disintegration of Uranium and Thorium is only the beginning of the story. These two nuclides give rise to a sequence of unstable elements which variously emit alpha, beta and gamma radiations. One of these is Radon, a radioactive but chemically inert gas. Radon gas, when it decays, produces a further series of radioactive elements.

The radon gas, heavier than air, can travel considerable distances and will concentrate in airless corners, generating a pocket of radioactive contamination with no apparent physical connection with the source of contamination.

Radon gas is found in the environment, and is troublesome in some areas of the world, giving rise to elevated radiation exposure to people in their own homes and offices.

Whilst not a massive problem, this represents the largest source of secondary contamination, and usually the most significant long-term health risk when considering the ownership of radioactive minerals.

## Good Radiological Working Practices

The essence of good radiological working practice is about the control and limitation of spread of contamination. The rules are quite simple:

- Do not eat, drink or apply makeup when working with radioactive materials
- Do not smoke where radioactive materials are in use
- Do not smoke where radioactive minerals are stored
- Do not touch anything you do not want to become contaminated with radioactive material
- Wear protective clothing (white lab coat/overall, disposable latex gloves etc.)
- Work only on a covered surface. Carefully fold and wrap the covering when work is complete, and package with used gloves etc. for disposal.
- Wash hands whenever you leave the work area or even when you have been wearing gloves.
- Contaminated mineralogical lab waste should be disposed of carefully and with a view to minimising the spread of contamination.

In addition, you should attempt to minimise the generation of waste. You should avoid raising dust or shrapnel from hammering or other cutting and trimming operations, since these particles are easily absorbed into the body or either through cuts, through inhalation or by ingestion.

Pets and children should be excluded from areas where radioactive or toxic minerals are being worked with.

Radioactive materials should not, under any circumstances, be stored or handled in any food-preparation area.

No food of any sort should ever be prepared where radioactive materials are being handled.

Smoke of its nature tends to collect Radon daughter products which are radioactive. It has been noted that the presence of blue smoke from cigarettes (the plume that rises from the burning tobacco) collects the radioactive radon daughter products more surely than any other means of concentration. This means that the spent smoke you breathe in a high Radon concentration area is bringing those radioactive materials into your lungs **in a form which tends to remain inside your body.**

If you are a smoker, then you should ensure that you do not smoke in the same room(s) as your radioactive specimens are kept, similarly, if you have smokers in your home, do not let them smoke in those parts of the house.

The consensus of scientific opinion is that a given dose from radon is possibly 10 or 15 times as dangerous to a smoker as to a non-smoker. (see Wozniak Dr SJ, Handbook of Radon)

## **Shielding**

We often hear discussion of radiation shielding, and most of us think immediately of vast slabs of lead. For a mineral collection, this is probably rather excessive.

In order to consider your shielding requirements we need to have a few pieces of information.

When beta particles are stopped suddenly as in, say, lead or steel, the energy they give up is released as X-rays, which are themselves akin to gamma radiation (*bremstrahlung* or braking radiation). If beta particles are stopped in lower density materials such as wood or hard plastic, the energy is dissipated as a very small amount of heat.

If a beta-emitter (and radioactive minerals are all beta emitters) is placed inside a lead-lined box, it is possible for the radiation dose-rate on the outside of the box to be higher than without the lead.

For this reason, it is usually preferable to keep radioactive minerals in boxes with a wooden interior, regardless of what the external structure is.

This has the advantage of providing a more resilient surface for the specimens in bags or boxes to rest upon. All wooden surfaces should be sealed.

With large amounts of radioactive material, the gamma radiation becomes problematical. Gamma photons are best absorbed in high density materials. Two materials that might be used are Barium sulphate (barite) powder and Lead.

Barium sulphate has the advantage that it is non-toxic. It is, however, a powder and is therefore difficult to use. It is also quite difficult to obtain cheaply in most places. It is often used as a constituent in plaster and in concrete in order to improve the shielding properties of these materials.

Lead has the advantage that it is a soft metal, easily worked and easily cut with a craft-knife. It is also readily available in foil form as lead flashing for domestic roofing purposes. The main disadvantage is that it is toxic, and is becoming increasingly expensive.

One or two layers of lead flashing outside of a wooden box will reduce the radiation from a large uranium specimen by a significant amount.

In order to reduce the radiation further, an old floor-safe will provide about 20% of steel shielding or the equivalent of about 1/40 of lead shielding.

## How much shielding is right?

This is like asking *how long is a piece of string?* The thickness and type of shielding you require depends on a number of factors: combined size of your specimens, situation of your storage, amount of time spent close to the radioactive minerals store etc.

Example calculation:

Assuming a source with gamma energy of 610keV, giving rise to a surface dose-rate of 32mR/h above background ó

Ignoring the build-up factor (which is difficult to calculate in),

8mm lead will reduce the dose to 16mR/hr

16mm will reduce it to 8mR/hr

24mm will reduce it to 4mR/hr

and so on.

In reality a radioactive mineral gives rise to a whole host of energies, which are attenuated to a greater or lesser degree.

Of course, lead is no longer the cheap commodity that it was, and it does have the disadvantage of being toxic. Its weight also makes it undesirable from a domestic point of view ó lead safes are notoriously difficult to move about.

Happily, the amount of radio activity of most mineral specimens is relatively small, most of the specimen being matrix. Thus, the dose rate in the proximity of a stock of radioactive minerals will be (in radiological terms) relatively low.

For most purposes, it is safe to assume that 6mm (¼ö) of lead in a steel or wooden cabinet will reduce the radiation dose in the immediate vicinity of the specimens to a reasonable level.

In addition, it may be safely assumed that specimens will shield each other to some degree ó especially if they are kept close together, rather than spread out in a well-spaced pattern. This gives us the opportunity to posit an alternative to the lead-lined cabinet.

## Other Factors

Sky-Shine, Back-Scatter, Spalling Radiation and Build-Up are terms that are often bandied about in Nuclear Safety circles, and represent factors that reduce the effectiveness of shielding. With the type and size of radioactive sources under discussion here, these factors are relatively insignificant.

## Radiological Instrumentation

At the very least, you will require a contamination meter ó this is a hand-held device that will indicate by means of a meter, a flashing light or a sounder (it makes a clicking noise) how much radioactive material is nearby.

A second type of instrument, known as a dosimeter or dose-rate meter indicates how much radiation there is (and how much damage it is doing to your body). These are traditionally calibrated in Roentgens per hour, RADS, REM, Greys (Gy) and Sieverts per hour. (See US NRC 20.1004, Units of radiation dose)

The type of contamination meter usually encountered uses a detector called a Geiger-Müller tube ó this type of device is commonly referred to as a *Geiger Counter*.

Contamination meters usually integrate (average) the reading over a period of 1 second, but integration over 5 or 10 seconds is not uncommon. The meter is usually calibrated in CPS (Counts Per Seconds) or CPM (Counts Per Minute). Occasionally the term *events* is used instead of *counts*.

Rarely the incorrect labels *Disintegrations per Second*, *Disintegrations per Minute*, *Curies (Ci)* and *Becquerels (Bq)* may be applied, and will require you to calibrate your instrument against a radioactive reference source.

Two further types of contamination meter are suitable for mineralogical work:

- A *scintillation detector* uses a different type of detector tube which is more expensive and more fragile than a standard Geiger-Müller tube ó and about a hundred times more sensitive.
- A *PIN Diode Detector* uses a special type of silicon photodiode to detect radiation. Although it is relatively insensitive, this type of device is incredibly robust, being virtually indestructible. It is only really suitable for detecting very large radiation sources and for certain types of radioassay.

Other detectors, generally of use for specialist applications and for radiation field (dose rate) measurements include Ionisation Chambers, Proportional Counters and Ion-Current Detectors (these last are used in smoke detectors). Scintillation detectors are also used in a very specialist device called a gamma-spectrometer, of which more later.

The choice of instrument is entirely your own ó based on availability, budget and advice from other collectors. Ideally, any instrument you take with you into the field will be light and easy to carry (and, mostly, waterproof). A lab/workshop instrument need not be portable, and may include a scaler-timer for radioassay use. These instruments should be of the *end-window* type for preference, as these give a pinpoint sensitivity. Windowless Geiger tubes are for gamma emitters only, and side-window types are intended for performing contamination surveys during radiological cleanups.

If you are concerned about radiation fields around your collection, a dose-rate meter is required. These should be calibrated professionally at regular intervals. Again, your choice of instrument is up to you, but a low-level environmental dose rate meter will be most

appropriate (a high-level meter will never give you a reading unless it is sat on your prize Betafite specimen ó if even then.)

If you are skilled in the building of electronics projects, then it is quite possible to build your own instruments ó to your own requirements, budget and satisfaction. With a little thought, it is quite possible to design an instrument for use in the field which can then be plugged into other equipment to become the detector stage of a laboratory radioassay set-up. There are numerous designs on the world wide web, as well as regular projects published in hobbyist electronics magazines.

If you are lucky, and have either the budget or happen upon a second-hand unit, then investment in a working scintillation detector type contamination meter is highly recommended ó preferably alongside a Geiger-Müller meter.

If you are extremely lucky, then a Gamma Spectrometer (or a window-comparator scintillation detector) will give you the ability not only to test how radioactive your specimens are, but to tell precisely which radionuclides (radioactive elements) are present. In fact there are two decay series that interest us (under normal circumstances), Uranium and Thorium ó you will be able to tell which of these chemically similar elements is in your specimen.

Gamma spectrometers are extremely expensive pieces of equipment, are extremely complex, and are wonderful for the kudos of ownership. For those of the mad-scientist persuasion, a *gamma-spec* is an absolute must-have ó even if non-functional, and will perfectly complement that *Scanning Electron Microscope* that you inherited from Uncle Igor.

For users of a technical bent, building your own assay rig should provide an interesting challenge, and will allow you to investigate the joys of proportional counters, ion chambers and solid-state detectors as well as any of several novel detection systems that amateur radiological investigators like to experiment with. This is, however, beyond the scope of this article.

For radio-assay, you will also require a counting castle, sometimes whimsically called a *lead oven*. The purpose of the castle is to reduce interference from background radiation (especially from nearby radioactive sources). Traditionally, these are constructed from at least several kilograms of lead. It is possible to build your own using plywood and lead flashing (a roofing material). Again, this is beyond the scope of this article. For gamma-spectrometry, there is no substitute for about 50kg (or more) of lead shielding, as this will cut out most of the background interference.

## **Test Sources**

You will require at least one radioactive test source with which to check your instrumentation. Please note that in no way does the author condone the obtaining or keeping of unnecessary radioactive sources.

The most popular is the Thorium Oxide Gas Mantle ó obtainable for a small amount from most hardware stores. Thorium mantles are now becoming rarer, but may still be found amongst old stock in some hardware stores.

Traditional domestic smoke alarms contain a small Americium source ( $^{241}\text{Am}$ ) which could be removed from an old unit (taking care not to put a finger over the aperture of the source ó the dose-rate at the surface is surprisingly high). This is primarily an alpha emitter, but will register on a thin-window Geiger-Müller tube. The activity of these sources is approximately 45kBq (0.1  $\mu\text{Ci}$ ) ó and does not require a licence in most countries. Newer smoke detectors use an infra-red LED, and so don't contain a radioactive source.

An old luminous clock or watch face will contain either radium ( $^{226}\text{Ra}$ ) or possibly Promethium ( $^{147}\text{Pm}$ ) as the energy source. Recently luminised instruments are powered by tritium ( $^3\text{H}$ ) sources that cannot be detected without specialist instruments. Many old aircraft instruments and military compasses contain enormous amounts of luminous paint.

For preference, if you use a luminous clock or watch, don't dismantle it, as this will help reduce contamination risks.

## Setting Up Your Lab

It used to be said that the key to a well-designed radiochemical laboratory was Formica, Formica, Formica. Certainly, you will require smooth, washable surfaces that can be easily decontaminated.

**Remember** that wood is porous, trapping particles of radioactive material and absorbing radon gas. For this reason, wooden surfaces should be sealed with a high gloss varnish (such as floor or yacht varnish) or with a hard-surface paint such as is used on cars.

The modern approach to radiochemical cleanup is to use disposable surfaces. Using a section of kitchen work-top (but NOT in the kitchen, please) is an excellent place to begin. This is then covered by a layer of impermeable paper – traditionally, Kraft Paper was used, this being two layers of heavy brown paper glued together using a tarry, pitch-like material. Currently products such as Benchkote are recommended – a white blotting-type paper backed with a thin layer of plastic.

An amateur radiological lab area might be furnished using a layer of 20-thou polythene sheeting taped to the bench surface, this is then covered with a layer of brown parcel-paper, also taped down, and the currently used working area covered with one or more layers of paper towelling or butcher's paper which are disposed of when work is finished.

Best of all, you might wish to work with your minerals kept in a paper-lined plastic or metal tray.

You will require some heavy-gauge polythene bags to use for waste disposal. It is usual to tape one of these to the front edge of the bench so that it hangs open, ready for waste to be put in immediately, without touching the outside of the bag. I recommend a roll of electrician's tape for sealing these bags when ready for disposal. These bags can also be used for simple glove-box operations.

You will require a supply of paper towelling, disposable examination gloves (preferably latex or vinyl. welded polythene gloves are simply not sufficiently robust). You will also require a wash-bottle of clean water with a couple of drops of washing-up liquid in it to wet a paper towel for wiping up any residues that become spread around.

You should also have a supply of plastic bags for putting specimens into, either for storage or for transport elsewhere. If you deal in micros and boxed thumbnail specimens, then a supply of suitable mounts should be on-hand.

You will require the usual supply of press-on labels, markers, pens etc. A notebook and a calculator (for use only in this work-area) should be available. Likewise, a set of specimen preparation tools should be available.

In an ideal world, you would have your lab set up so that you have a foot-barrier and sealed flooring etc. Inside the barriered area you should wear a lab-coat, cloth or disposable overshoes and gloves, and you would prevent any radioactive material from crossing the barrier. This being an amateur set-up, you should have a linoleum/vinyl floor covering (even if it is just a small square in front of your bench) so that you can clean up any spillages easily.

I continue to recommend the use of overshoes (these are cloth or plastic bags worn over your shoes) to prevent you from tracking radioactive debris around your house. I also recommend the use of a white lab-coat to protect your clothes from contamination. These

should be removed when leaving your lab area, and should be washed frequently ó possibly even after each use.

Your work area should be set up for your own convenience. You have to work there, so you decide where everything goes.

You will need to be able to wash your hands when you leave the work area ó and you will need to do this with *running water*, not an alcohol-based cleanser or pre-moistened towels.

Set up your equipment in such a way that it is easily accessible, and so that fixed equipment won't become contaminated when you are preparing radioactive minerals for storage, investigation or display.

If you use multiple networked computers, it is worth using an old one as part of your laboratory set-up, that way you don't have to worry about decontaminating keyboard and mouse every time you work on your radioactive specimens.

If you have a radioassay set-up, it is worth mounting your counting castle on a raised section of bench-top (maybe an extra thickness of counter-top placed on the bench). This is in order to limit the spread of contamination in close proximity with the equipment.

Counting equipment should be kept clean and clear of radioactive contamination, since this will maintain its accuracy for many years.

## Labelling and Signage

It is a good idea to place appropriate signs to indicate to a visitor to your lab that there is the risk of exposure to radioactive materials. The standard signage varies from country to country, but the example to the right is clear enough as to be unambiguous.

The radiation trefoil is, regardless of any other details, a universal symbol for a radiation or radioactive materials hazard.

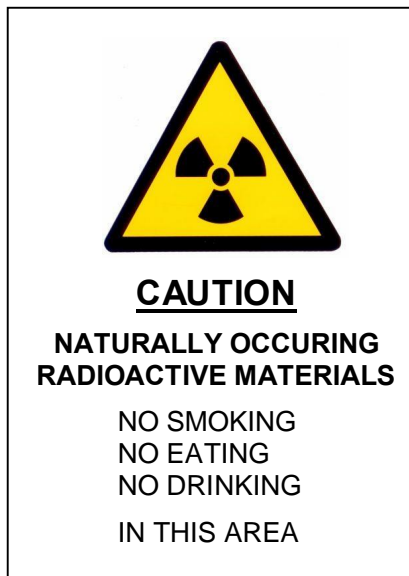


A circled trefoil is the usual indication that a container encloses radioactive material, regardless of the activity of the contents and the dose-rate at the surface of the container.

Individual specimens may have their radioactive nature displayed on their labels using a circled trefoil, or, in storage, it is advisable to label them as for any other hazardous material.



The two hazardous materials symbols that exist ó the trefoil alone on the older style of *Radiation Hazard* flash, and the newer (and more complex) *Radio-Toxic Materials* flash, are shown to the left. Appropriate accompanying text may be as follows:



### **Caution Radioactive Material**

(Naturally Occurring Minerals)

Do Not Handle Excessively  
Wash Hands After Examination

Store Away From Foodstuffs  
Store Away From Photographic Materials

## **Shielded Storage**

Lead lined strong boxes are relatively easily made by using a document box, a few millimetres of lead and a wooden liner will produce an extremely effective radioactive safe for a few specimens, and this can be duplicated to increase the storage capacity. These smaller storage boxes, while still heavy, are individually manageable in a way that a larger safe is not.

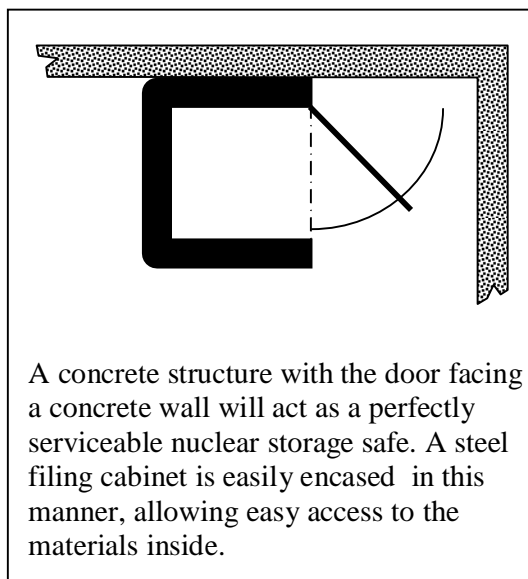
Another kind of shielding, whilst not moveable at all, is easily fabricated in a garage or permanent work-room. A few inches of concrete will take the place of an inch or so of lead, and a permanent storage cabinet will take but a few hours to construct and fit out.

Please note that solid concrete should be used, and not cellular cement blocks or cavity blocks (they don't contain enough concrete to act as shielding at all.)

A lightweight door may be used if the door-opening faces a solid wall as shown to right. An alternative, and preferable to a shelved cupboard, would be to build the structure around a steel filing cabinet by combining security and shielding in one operation. Remember that sufficient space must be left to allow the drawers to be installed and removed as well as simply being opened.

Note that access to the space between the concrete-shielded cabinet and the facing wall should be restricted, as it is largely unshielded.

For really large and comprehensive collections of radioactive minerals, both a concrete-shield and lead-lined strong boxes within may be advisable.



A concrete structure with the door facing a concrete wall will act as a perfectly serviceable nuclear storage safe. A steel filing cabinet is easily encased in this manner, allowing easy access to the materials inside.

All contaminated (or potentially contaminated) waste should go in the waste bag, which will be taped closed for disposal. The waste bag should then be placed inside another bag, which is also sealed closed. (This is called *double bagging*).

Where specimen trimming is carried out, this should be done with the specimen and tools inside a clear 20-thou polythene bag to prevent spreading of radioactive debris.

Where possible, work in a way that doesn't raise dust so keep hammering and dry-cutting to an absolute minimum. For preference, a wet saw or splitter should be used.

Work in a fashion that doesn't cross-contaminate specimens, and doesn't spread radioactive contamination across your bench, and remember to clear up any mess immediately. This means a lot of wiping down, but it is worth the effort.

This is a specialist area of work, and is sensible when you are collecting radioactive minerals seriously. Radiological assay falls into two broad categories, Audit Counting and Diagnostic Assay.

- Audit Counting

This is simply the accurate assaying of how much radioactivity each specimen represents, and may be used as a basis for decisions on the necessary storage, display and handling requirements for a specimen. It can also give you an indication of the richness of an ore sample.

- Diagnostic Assay

This is an analytical procedure, usually requiring a gamma spectrometer or window spectrometer set-up. With this equipment it is possible to determine the identity of the radionuclides present in your specimens.

## Disposing of Your Contaminated Waste

For further information, please check your local ordinances. At the time of writing, there was no control of small amounts of radioactive mineral waste in any part of the United Kingdom.

Some individuals may prefer to concentrate their contaminated waste for disposal through a specialist disposal route. Whilst this may be perfectly sound practice in many instances, dilution and dispersal (as in domestic waste) is generally considered a reasonable approach for the tiny amounts of radioactive material produced by mineral collectors, but you should consult your local ordinances to be sure.

As a general rule, in administrations where no control exists on naturally occurring radioactive materials, there is unlikely to be any control of unprocessed mineral waste.

Mineral waste should not, generally, be disposed of by burial in any place where heavy metals can contaminate groundwater. Similarly, mineral waste should not be placed in any location easily accessible by children, pets or livestock.

In addition, in the case of radioactive minerals, mineral waste should not be disposed of by burial close to or under (for example, as part of the foundation footings) any dwelling or other building due to the risk of elevated radon concentrations in the structure.

## Storing and displaying your specimens

The question of how to store and to display your radioactive minerals is probably more significant than how to work with those minerals.

To answer this question, we need to take a number of factors into consideration:

- How much radioactive material do you have?
- How well ventilated is the storage location?
- Do you wish to display your specimens?
- Where is your storage/display location sited?

If you only have a few small specimens, then the answer is simple ó store them in zip-lock style polythene bags kept in a wooden or plastic box inside a locked cabinet or drawer, or display them in a locked glass-fronted display case with at least a few inches between the specimen and the glass/wooden front/side/top/back etc.

If you have larger quantities of radioactive mineral, then the problems of storage and display become more complex.

The reinforcement of the radiation field by multiple larger-activity specimens means that it is advisable to reduce the radiation dose acquired by their proximity as far as is practically possible. The most obvious way is to remove the specimens to a part of the house less-frequently occupied.

If moving your minerals to a spare room, especially a spare bedroom, it is important to remember that the radiation arising from those specimens will penetrate walls, floors and ceiling to some greater or lesser extent. Nuclear radiation is no respecter of room-boundaries, and you may find that you are now sleeping with your radioactive specimens under your bed, albeit on the floor below.

### ***Storage of Larger Amounts of Radioactive Mineralogical Material***

Radioactive minerals should be stored in sealed zip-lock type bags, these bags in turn to be placed in plastic containers, such as sealable Tupperware<sup>®</sup> boxes. Delicate specimens may be placed in boxes which are in turn placed in zip-lock bags.

Labels should be attached to the outside of the storage bags in order to ensure continued readability without opening the bags. Alternatively, a smaller specimen may be placed in a sealed bag, which in turn is inside the next bag size up along with the label.

The outside of the sealable boxes should be clearly and indelibly marked as containing radioactive material, and should never be returned to food use.

When accessing the specimens the boxes should be opened only with gloved hands, and the bags opened only when necessary. Both boxes and bags should be opened in a well-ventilated location and should be allowed to air-out for at least an hour in order to allow the short-lived Radon daughter products to decay.

Boxes of specimens should be kept in a locked cabinet of some type. For sound radiological reasons, the cabinet should be wooden or thick (at least 3mm - 1/8" Aluminium), or else a steel cabinet/drawer etc. lined with at least 1/4" of wood or hard plastic. Wood should be thoroughly sealed with a high-gloss varnish (such as floor or yacht varnish) or a hard paint surface. A wooden or plastic lining provides a safe buffer between the specimens and the outside wall, and will shield the beta radiation quite adequately.

If large numbers of high activity specimens are envisaged to be stored, then a thick layer of lead (at least 3mm - 1/8") should be placed between the wooden lining and the exterior structure of the cabinet. Here the wood or plastic will absorb the beta radiation and the lead will absorb part of the gamma radiation.

Under these circumstances, it is a good idea to have some kind of ventilation between your storage cabinet and the outside world in order to allow the escape of any radon build-up in the closed cabinet.

## ***Display of Larger Amounts of Radioactive Mineralogical Material***

Radioactive mineral specimens, when put on display, require some extra thought in their placement and disposition.

It is a good idea to place larger radioactive specimens in a clear plastic tray, or to mount them on a plastic base in the display case. This facilitates both handling without touching the specimen, and the catching of any loose material that should fall from the specimen.

Thumbnail and miniatures should be permanently mounted in the usual way, as this serves the same function.

Highly radioactive specimens should be displayed in cases placed against a solid or exterior wall, and should be placed toward the rear of the case in order to maintain the maximum distance between the specimen and the observer.

Again, in order to maintain maximum separation between observer and specimen, radioactive specimens should not be placed to the side of a display case where that side is accessible to pedestrian traffic.

Because of the long-term exposure risks, large numbers of radioactive specimens should not be displayed in locations where you sit or entertain guests. Nor, ideally, should specimens be displayed in a dining room unless great pains are taken to ensure that there is no contamination arising from them.

The radon hazard arising from keeping Uranium and Thorium minerals in an airtight cabinet becomes readily apparent by the steady build up of radiation dose at the outer surface of the cabinet, caused by radon daughter nuclides settling on the inside surfaces of the display. While this is never likely to be that large, it is measurable with basic instruments.

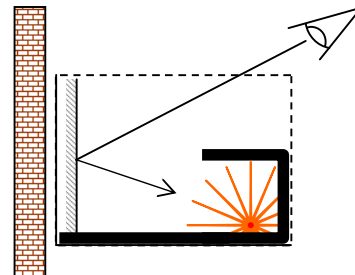
The ideal display will be vented to the outside of the building, otherwise the cabinet must be left to air for at least a few hours to allow the radon daughters to decay before rearranging the display.

A non-airtight display cabinet, especially one that is properly vented will not suffer a build up of radon, but it will allow there to be a build up elsewhere in the house.

Flat (top-viewing) display cabinets should be deep enough to allow at least a few inches of air-gap between the specimen and the glass. It may be advisable to "double-glaze" this type of cabinet in order to further reduce the acquired dose from larger specimens.

Where access to the underside of the cabinet is possible, it may be advisable to reinforce the base with a layer of lead and a layer of ply-wood.

An alternative, popular in museums, is to have a fully shielded case with one open side facing the wall. Viewing of the specimens is via a mirror placed against the wall behind the cabinet, as illustrated to the right.



## Interpreting Dose-Rate measurements

If you are seriously concerned about your radiation exposure, then you will want to measure the radiation dose-rate in the vicinity of your specimens, and then to interpret those results. For this you will require access to an Environmental Dose Rate Meter.

This instrument measures the radiation field in your environment, and should give you a measurable reading anywhere. If the instrument gives a reading of zero, then it is not sensitive enough for our purposes.

### ***Environmental dose-rate***

No matter where you go, there will always be some nuclear radiation. Much of this background radiation comes from the sun (actinic radiation); a tiny amount comes from the stars (cosmic radiation). However, a significant part of the background radiation we experience comes from the Earth itself.

Many natural materials are radioactive including you. This has always been true, even before Mankind developed nuclear devices.

We all think of such things as Uranium being radioactive, but a proportion of all Carbon in living things is radioactive, a proportion of all Hydrogen is radioactive, and so is a proportion of all Potassium. All three elements form part of the human body.

The average annual radiation dose is approximately 2.0 mSv, although this varies from place to place, generally being higher where igneous rocks abound.

The main contributing factors to this annual background dose are:

Cosmic radiation (latitude and altitude related)	0.3 mSv
Radioactivity from rocks, soil, buildings (geology related)	0.3 mSv
Radioactivity in human body (mainly $^{14}\text{C}$ , $^3\text{H}$ and $^{40}\text{K}$ )	0.4 mSv
Inhaled Radon and daughter products (geology related)	1.0 mSv

**The actual annual dose may vary from 1.0 mSv up to (in extreme cases) 200 mSv.**

The risk of cancer formation is generally accepted to be negligible at doses of up to 100 times the background radiation dose, though presumably not where the dose rate is already high. Certainly diagnostic radiation doses will put an individual's annual dose up significantly, without measurably raising the risk of cancer.

## ***Dose Recommendations***

Whilst diagnostic X-rays may deliver several times these levels, the current limit (United Kingdom, October 2008) laid down for the Annual Dose Limit for Classified Radiation Workers is 20 mSv; non-radiation workers and the general public are permitted 1.0 mSv received as an *occupational dose* (i.e. from radiation-utilising processes in your work environment). It is probably a good idea to stick with this latter as your target for Annual *Hobby Dose Limit*. However, for most people estimating their annual dose, this may be unachievably low, especially since the calculations will usually be based on a worst reasonable case prediction.

## ***How much is too much?***

It has been estimated that the typical handling of radioactive minerals in a general mineralogy collection typically amounts to about 10 hours per year with an average handling radius of about 100mm.

Achievement of the maximum annual dose (about 1 mSv) can be reasonably taken as being of acceptably low risk. This would mean that handling radioactive minerals for those 10 hours with an average dose of 100 Sv/hr would not exceed this limit. Of course, smaller radiation sources could feasibly be handled for proportionately longer.

Similarly, a mineral sourcing 1mSv/hr would result in achieving this dose limit in only one hour.

## ***Risk Assessment and Dose Limits***

The annual dose limits set by the various nuclear agencies are calculated in order that the risk from occupational exposure to radiation does not appreciably increase that risk encountered through normal environmental radiation exposure. In fact, the 1mSv limit is equivalent to the additional radiation encountered during a high-altitude transatlantic flight.

By allowing yourself to become exposed to increasing levels of radiation, you are increasing your risk of contracting radiation-induced disease, mainly various forms of cancer. At significantly higher dose levels, specific organs can become compromised by specific damage. The most obvious organs at risk from working with radioactive specimens are the skin of the hands and the eyes (which are particularly at risk from hard alpha and beta radiations).

Your radiation dose comes in two ways: chronic low level exposure and occasional elevated exposure. The first of these is probably the more significant.

## **Chronic Low Level Exposure**

This is the radiation dose you acquire through the elevation of the background radiation in your home environment. A 1.0  $\mu\text{Sv/hr}$  rise in dose will, for a typical working adult, result in a dose of up to about 6.5 mSv over the year.

Ideally, you will work toward reducing your estimated annual Hobby Dose to a level indistinguishable from natural background radiation. For most mineral collectors, this is no hardship, as a few smallish cabinet specimens or a selection of thumbnail specimens will not raise the environmental background in a dwelling by any appreciable amount.

On the other hand, serious collectors of radioactive minerals with large specimens with a high activity will need to consider carefully the disposition of their collection. An increase of above 0.1  $\mu\text{Sv/hr}$  over background, averaged through a dwelling, is to be strongly discouraged.

## Periodic Elevated Exposure

This dose occurs whenever radioactive materials are being handled. While it is very difficult to quantify the dose acquired during the examination and preparation of a mineral specimen, dose reduction is fairly easily achieved.

Not all of the following precautions are necessary, since not all specimens are sufficiently radioactive to warrant the more extreme measures. However, it is worth getting used to the procedures, if more active specimens are likely to be acquired.

1. Minimise handling time by being well prepared for the work being undertaken, and by planning the preparation and examination operations.
2. Use shielding wherever possible.  
Uranium and Thorium minerals are strong beta-emitters, and may produce particularly powerful alpha radiations. Work with a clear acrylic face shield in order to reduce facial exposure to these more damaging radiations.  
The use of lead shielding (or equivalent) between the specimen and your body is highly recommended. Several millimetres of lead sandwiched between plywood is excellent for all but the most intensely active specimens.
3. Use remote handling.  
Use rubber gloves in preference to bare fingers and use tongs pliers or forceps in preference to gloved hands. The most intensely active specimens should never be handled directly.

## Doses to Eyes and Face

This is an often overlooked area of radiation protection. The face is the most vulnerable part of the body to radiation when working with mineral specimens.

Whilst the fingers may receive a larger radiation dose while preparing and handling mineralogical material, the face actually exposes living tissues to the world with no horny layer of skin to protect it. The eyes and mouth, and to a lesser extent the nose, are unshielded from alpha or beta radiations.

The main symptom of severe eye-exposure is the formation of milky cataracts. That of lip and similar mucous tissue exposure is similar to severe sunburn. Long-term effects may also include the appearance of cancerous tumours.

When working with naturally occurring radioactive materials, eye protection is required. Safety glasses or ordinary spectacles absorb the hard alphas arising from some of the decay-chain nuclides as well as partially shielding the eyes from beta radiation.

A bench-mounted face shield of at least a few millimetres of clear acrylic is most highly recommended. For collectors of extremely high activity mineral specimens, a proprietary lead-acrylic co-polymer face shield is definitely recommended.

Under no circumstances should a radioactive specimen be examined through a small hand-lens or a jeweller's loupe, as this will expose the eye and surrounding tissue to the elevated dose found in close proximity to the specimen.

## Activity and Dose-Rate Calculations

The value of Specific Activity for the species listed in Part II is calculated based on the radioactive isotope abundance in a pure specimen of the mineral concerned. This makes certain assumptions of the actual composition. By using the figures for aged samples, that is samples where the daughter nuclides are in secular equilibrium with the parent nuclide, we may estimate both specific activity and dose-rate at one meter from the specimen.

In order to calculate the specific activity of a particular nuclide, we need to know the half-life of the nuclide, that is the time taken for half of the radioactive atoms to decay. This is achieved as follows:

$$A = \lambda N$$

Where  $A$  is the activity of a sample of the nuclide,

$\lambda$  is the decay constant,

$N$  is the number of radioactive atoms present in the sample.

The decay constant,  $\lambda$ , is given by the formula

$$\lambda = \frac{0.693}{t_{1/2}}$$

Where  $t_{1/2}$  is the half-life of the nuclide in seconds.

$N$  is given by

$$N = \frac{mA_0}{G_a}$$

Where  $A_0$  is the Avogadro Constant (the number of atoms in a gram-mole of the nuclide)

$m$  is the mass of the nuclide

And  $G_a$  is the gram-atomic weight of the nuclide.

The Avogadro Constant is numerically equal to  $6.02214179 \times 10^{23}$

Thus, for 1 gram of a nuclide ( $m=1$ ), we have:

$$A_{sp(n)} = \frac{0.693 \times 6.02214179 \times 10^{23}}{G_a \times t_{1/2}}$$

Remember that the conversion for  $t_{1/2}$  from years to seconds is:

$$t_{1/2}(\text{seconds}) = t_{1/2}(\text{years}) \times 31557600$$

For single nuclides, this calculation is simple. For decay series, such as the  $^{238}\text{U}$ ,  $^{235}\text{U}$  and  $^{232}\text{Th}$  series encountered in nature, the calculation has to be carried out for each nuclide in the decay series. For these series, it is simpler to use the calculated values for specific activity tabulated in many reference books.

Converting from nuclide specific activity to molecular specific activity requires some further maths. Thus, given that:

- $M_n$  = Molar mass of radionuclide
- $M_m$  = Molar mass of mineral
- $A_{sp(n)}$  = Specific activity of nuclide (aged)
- $A_{sp(m)}$  = Specific activity of mineral (aged)
- $m_{(s)}$  = Mass of mineral in sample
- $A_{(s)}$  = Activity of sample

We can state that:

$$A_{sp(m)} = \frac{M_n}{M_m} \times A_{sp(n)}$$

And that:

$$A_{(s)} = m_{(s)} \times A_{sp(m)}$$

Dose rates are calculated using the following formula:

$$D_r = \frac{D_o}{r^2}$$

Where  $D_r$  is the dose rate at radius  $r$ ,  
 $r$  is the radius (distance in metres) from the radiation source  
 and  $D_o$  is the dose-rate at 1metre.

So, at 0.1m (100mm) the dose rate will be 100 times higher,  
 at 0.01m (10mm) the dose rate will be 10 000 times higher,  
 at 0.001m (1mm) the dose rate will be 1 000 000 times higher  
 and at 2.0m the dose rate will be 4 times smaller.

Whilst, mathematically speaking, this would result in an infinitely large dose rate in contact with the radioactive source, in reality this is not the case. Because specimens are real objects with relatively low specific activity, we can consider the minimum effective radius to be about 10mm (about the width of a fingertip).

The exception to this rule of thumb is *Radian Barite*, which is potentially of sufficiently high activity to be appreciably hazardous to handle closely; here we must assume this minimum radius to be about 1mm.

We can estimate the dose-rate at one meter from the sample, since the dose rate will be that of a sample of the "pure" nuclide concerned with the activity  $A_{(s)}$ .

Since the nuclides under consideration are mixed alpha, beta and gamma emitters, there will be a slightly more rapid fall-off of dose rate than calculated due to absorption of high-energy alpha and beta radiations in the air.

The specific activities (in Becquerels per gram ó Bq/g) of a range of naturally occurring radionuclides has been determined, and are listed in the table below. The radiation dose received at 1m from the pure material has also been estimated, and is included in the table. For normal handling, we tend to use the dose rate at 100mm as a mean value.

Element (Nuclide)	Nuclide	Molecular Mass Natural Isotopic Abundance	Abundance	Specific Activity Natural Isotopic Abundance	Dose Equivalent at 1m	Half Life	Decay Modes
	* = Decay Series <sup>235, 238</sup> U*	AMU	%	Bq/g	Sv/hr	Years	
<b>Uranium</b>	<sup>238</sup> U*	238.02891	100.000	<b>1.79001 x10<sup>5</sup></b>	<b>2.24</b>	4.483 x10 <sup>9</sup>	α, β, γ
<b>Thorium</b>	<sup>232</sup> Th*	232.03806	100.000	<b>4.48006 x10<sup>4</sup></b>	<b>5.68 x10<sup>-01</sup></b>	1.390 x10 <sup>10</sup>	α, β, γ
<b>Radium (Ra)</b>	<sup>226</sup> Ra*	226.00000	100.000	<b>3.70000 x10<sup>10</sup></b>	<b>5.16 x10<sup>5</sup></b>	1.602 x10 <sup>3</sup>	α, β, γ
Bismuth	<sup>209</sup> Bi	208.98030	100.000	2.34375 x10 <sup>-5</sup>	6.52 x10 <sup>-14</sup>	2.700 x10 <sup>18</sup>	α
Platinum	<sup>190</sup> Pt	189.95990	0.013	1.31163 x10 <sup>-2</sup>	3.65 x10 <sup>-11</sup>	6.900 x10 <sup>11</sup>	α
<b>Rhenium</b>	<sup>187</sup> Re	186.95570	62.900	<b>1.03472 x10<sup>3</sup></b>	<b>2.88 x10<sup>-06</sup></b>	4.300 x10 <sup>10</sup>	β
Osmium	<sup>186</sup> Os	185.95380	1.580	5.61827 x10 <sup>-4</sup>	1.56 x10 <sup>-12</sup>	2.000 x10 <sup>15</sup>	α
Tantalum	<sup>180</sup> Ta*	180.94788	0.012	7.35401 x10 <sup>-6</sup>	2.04 x10 <sup>-14</sup>	9.006 x10 <sup>17</sup>	α, β, γ, ε
Tungsten	<sup>180</sup> W	179.94670	0.120	4.89942 x10 <sup>-8</sup>	1.36 x10 <sup>-16</sup>	1.800 x10 <sup>18</sup>	α
<b>Lutetium</b>	<sup>176</sup> Lu	175.94260	2.590	<b>5.15012 x10<sup>1</sup></b>	<b>1.43 x10<sup>-07</sup></b>	3.780 x10 <sup>10</sup>	β, γ
Hafnium	<sup>174</sup> Hf	173.94000	0.163	6.19638 x10 <sup>-5</sup>	1.72 x10 <sup>-13</sup>	2.000 x10 <sup>15</sup>	α
Dysprosium	<sup>156</sup> Dy	155.92420	0.052	4.41032 x10 <sup>-8</sup>	1.23 x10 <sup>-16</sup>	1.000 x10 <sup>18</sup>	β
Gadolinium	<sup>152</sup> Gd	151.91970	0.200	1.58272 x10 <sup>-3</sup>	4.40 x10 <sup>-12</sup>	1.100 x10 <sup>14</sup>	α
<b>Samarium</b>	<sup>147, 148, 149</sup> Sm	150.36000	40.190	<b>1.27302 x10<sup>2</sup></b>	<b>3.54 x10<sup>-07</sup></b>	9.109 x10 <sup>16</sup>	α
Neodymium	<sup>144</sup> Nd	143.91000	23.800	9.55060 x10 <sup>-3</sup>	2.66 x10 <sup>-11</sup>	2.290 x10 <sup>15</sup>	α
Cerium	<sup>142</sup> Ce	141.90920	11.080	2.06509 x10 <sup>-4</sup>	5.74 x10 <sup>-13</sup>	5.000 x10 <sup>16</sup>	α
<b>Lanthanum</b>	<sup>138</sup> La	137.90710	0.090	<b>8.23779 x10<sup>-1</sup></b>	<b>2.29 x10<sup>-09</sup></b>	1.050 x10 <sup>11</sup>	β, γ, ε
Tellurium	<sup>122</sup> Te	122.90420	0.908	8.14176 x10 <sup>-2</sup>	2.26 x10 <sup>-10</sup>	1.200 x10 <sup>13</sup>	ε
<b>Indium</b>	<sup>116</sup> In	114.90380	95.710	<b>2.49784 x10<sup>-1</sup></b>	<b>6.94 x10<sup>-10</sup></b>	4.410 x10 <sup>14</sup>	β
Molybdenum	<sup>100</sup> Mo	99.90740	9.630	1.63423 x10 <sup>-6</sup>	4.54 x10 <sup>-15</sup>	7.800 x10 <sup>18</sup>	2β
Zirconium	<sup>94, 96</sup> Zr	91.22400	20.180	2.22699 x10 <sup>-4</sup>	6.19 x10 <sup>-13</sup>	2.870 x10 <sup>18</sup>	2β
<b>Rubidium</b>	<sup>87</sup> Rb	86.90910	27.835	<b>8.91687 x10<sup>2</sup></b>	<b>2.48 x10<sup>-06</sup></b>	4.750 x10 <sup>10</sup>	β
Vanadium	<sup>50</sup> V	49.94710	0.250	8.09030 x10 <sup>-6</sup>	1.28 x10 <sup>-10</sup>	1.500 x10 <sup>17</sup>	β, γ, ε
Chromium	<sup>50</sup> Cr	49.94600	4.345	6.39141 x10 <sup>-5</sup>	1.01 x10 <sup>-09</sup>	1.800 x10 <sup>17</sup>	2ε
<b>Potassium</b>	<sup>40</sup> K	39.96390	0.012	<b>3.03185 x10<sup>1</sup></b>	<b>4.79 x10<sup>-04</sup></b>	1.277 x10 <sup>9</sup>	β, γ, ε

Decay mode ε = electron capture (with an accompanying gamma ray)

Radiologically significant nuclides are highlighted in **bold**.

Note that the presence of many elements in a mineral, and particularly the Rare Earth Elements may indicate, at least under certain conditions of formation, a certain level of Thorium or Uranium as an impurity.

## ***Self-shielding***

Given the density of most rocks found as the matrix upon which radioactive minerals are deposited, and given the density of the radioactive minerals themselves, we often find that the activity and dose-rate measurements of larger specimens is appreciably lower than predicted by calculation. This is, in part, due to the presence of dense material between the radiation source and the detector.

This *self-shielding* effect is found to limit, in some cases, the measured apparent activity and dose rate arising from extremely large specimens to some finite limit. Certainly, it simplifies the handling of some strongly radioactive species by providing a "handle" for the specimen concerned.

No account is made of self-shielding in this handbook as the physical size of the radiation sources as well as their activity levels makes these calculations unnecessarily complex.

## Conclusions

In summary, it is possible to state with some confidence, that with care and consideration it is possible for an amateur to handle radioactive minerals safely. Throughout dealing with these materials, consideration must be made as to the risks, and the responsibilities of those collectors, especially around young people.

With a little ingenuity, a suitably equipped laboratory area is within most collectors' reach. Likewise, a safe way of displaying prize specimens of radioactive minerals is not unreasonable.

By storing and displaying specimens away from frequently used living areas, the radiation dose may be reduced greatly, and by arranging specimens carefully and with consideration of the safety implications, then the dose may be reduced even further.

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## **Part III**

A key to the radiological considerations of mineralogical species

### **Arrangement of Part III**

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## The Naturally Occurring Radionuclides

There are a relatively small number of radioactive elements that occur in nature. Two of these ( $^3\text{H}$  and  $^{14}\text{C}$ ) are generated by bombardment of water and carbon dioxide by hard solar radiation high in the atmosphere. These short-lived nuclides (by geological standards) are incorporated into living organisms, but will have decayed to inactivity by the time any fossilisation processes have occurred.

The nuclides that are encountered in a geological setting are:

Uranium	A mixture of $^{238}\text{U}$ and $^{235}\text{U}$ , and all of their radioactive daughter products	
Thorium	A mixture of $^{232}\text{Th}$ , and its radioactive daughter products.	
Potassium	$^{40}\text{K}$	
Lanthanum	$^{138}\text{La}$	Rare earth Elements
Cerium	$^{142}\text{Ce}$	
Neodymium	$^{144}\text{Nd}$ & $^{150}\text{Nd}$	
Samarium	$^{147}\text{Sm}$ , $^{148}\text{Sm}$ , $^{149}\text{Sm}$	
Europium	$^{151}\text{Eu}$	
Gadolinium	$^{152}\text{Gd}$ , $^{160}\text{Gd}$	
Lutetium	$^{176}\text{Lu}$	
Rhenium	$^{186}\text{Re}$	
Rubidium	$^{85}\text{Rb}$	
Radium	$^{226}\text{Ra}$ is a relatively short-lived daughter product of Uranium decay that can become chemically concentrated under certain along with its radioactive daughter products.	
Bismuth	$^{209}\text{Bi}$ is of academic interest only, since its activity is so low that it is not normally assumed to be radioactive at all.	
REE	A generic mixture of rare-earth elements (including Lu, Re, Rb, Sm)	

Also, there are naturally occurring radioisotopes of Chromium, Indium, Molybdenum, Osmium, Platinum, Tungsten, Tantalum, Vanadium and Zirconium, none of which is singularly significant for radiological protection purposes.

There is evidence of other, relatively short-lived nuclides in the Oklo Reactor Deposits in Gabon such as Plutonium. These were generated by the prolonged fission reaction cycles that occurred in this location during the Precambrian period, and probably formed minerals that are no longer possible to find in nature. The uranium ores from the reactor zones of the Oklo deposit are notable for being  $^{235}\text{U}$  deficient, and will therefore present a marginally reduced activity (by about 0.6%).

## The Radiochemistry of Minerals

### *Thorium and Uranium minerals*

These minerals have similar, complex chemistries. Many of the minerals exist as solid-solution series between the Uranium and Thorium analogues. There is no such thing as a pure Uranium or Thorium mineral, as there are always the chemical by-products of the radioactive decay products which are typically metals with chemistries very different from Uranium and Thorium, indeed, not all of the decay products are even metals (Astatine is a halogen and Radon is an inert gas). The most radioactive minerals of these two elements are *Uraninite* and *Thorianite*.

### *Radium Minerals*

Occasionally, circulating ground waters will dissolve out the Radium ( $^{226}\text{Ra}$ ) from Uranium mineral deposits (Radium salts are typically more soluble than Uranium compounds), which will then be deposited elsewhere.

This radionuclide is typified by a single mineral, *Radian Barite* (*q.v.*). This mineral is deposited rapidly, and decays with a half-life of 1602 years. There are no other recognised mineral species containing Radium other than in equilibrium with its parent nuclide,  $^{238}\text{U}$ .

Radian Barite can become deposited spontaneously in the pumping and circulating equipment of oil-drilling equipment, giving rise to a serious, and unexpected radiation hazard. This mineral is characterised by being highly radioactive, which activity will decay appreciably over a period of a few decades.

### *Rare Earth Elements*

This is a group of 17 chemically related metallic elements: Lanthanum, Cerium, Praseodymium, Neodymium, Promethium, Samarium, Europium, Gadolinium, Terbium, Dysprosium, Holmium, Erbium, Thulium, Ytterbium and Lutetium.

For most purposes the minerals containing some mixture of these elements are treated as containing a single pseudo-element called REE  $\phi$  which has a low specific activity and a vanishingly low dose-rate associated with it. For most practical purposes REE minerals may be treated as being non-radioactive.

However, many REE minerals **are** radioactive. In nature, at least some of the rare earths are substituted with other elements, and this frequently includes Thorium, and more rarely Uranium. It has been suggested that at least a few non-active specimens showing signs of radiation damage may even have been substituted by the short-lived nuclide Radium-226.

For the purposes of calculation in the absence of radiation detection equipment, about 5% of the REE should be assumed to be substituted by Thorium. Being a worst-case, this figure is deliberately high, the typical levels being of the order of 0.1% to 1%. There *are* approximate ways to distinguish substituted and unsubstituted REE minerals by eye, and these are dealt with in the section on field collecting.

### ***Rhenium and Rubidium***

These two elements display a moderate level of radioactivity along with a very low dose-rate in the nSv/hr range. Minerals containing these elements are appreciably radioactive, though they require little special handling unless held in large amounts.

### ***Potassium Minerals***

This nuclide forms part of all living things as well as many minerals. The small level of radioactivity arising from Potassium is largely insignificant, but may reasonably be taken into account when performing radioassay on mineral specimens. Potassium-40 provides a useful calibration peak when using gamma spectrometry with mineral specimens.

### ***Bismuth***

To all intents and purposes, with a vanishingly small specific activity and very low energy of decay, Bismuth may be treated as non-radioactive.

## ***Toxicity of Radioactive Materials***

All minerals carry some risk of toxic effects if absorbed into the body. Obvious materials, such as Arsenic and Thallium compounds spring to mind. Copper, a metal vital to the correct functioning of our bodies, becomes toxic when absorbed in quantities over a few micrograms per day.

Many metals, known as heavy metals, including lead, mercury, thallium, uranium, and thorium, are toxic to the human organism at quite low levels. In the case of uranium and thorium, this toxicity can exceed their danger as radioactive materials by a large factor.

A number of terms are useful here:

### ***Biological Half-Life***

The time taken (under normal circumstances) for half of a chemical to be eliminated from the body by excretion. Biological half-life can be altered by environmental and dietary conditions.

In the case of Iodine-131 (in the event of release in nuclear accident) the biological half-life can be reduced by saturation of the body with non-radioactive iodine (in the form of potassium or sodium iodide). The radioactive iodine begins to be excreted rapidly within a couple of hours.

### ***Acute Effects***

These are effects that often have their onset rapidly, are usually severe and possibly life-threatening in the short-term ó hours, days, weeks or months.

### ***Chronic Effects***

These effects are usually experienced as low-level symptoms over a period of months, years or even decades. Injury or symptoms may be unchanging (static) or progressive. Remission (if it occurs) of the symptoms usually occurs over a period similar to the period of onset of the symptoms.

### ***Cumulative Effects***

These effects build progressively over time, progressively worsening, usually in conjunction with continued exposure to the source of the effect.

### ***Permanent Effects***

This is damage that can never be repaired by the body. Hepatotoxic effects (liver damage) and neurotoxic effects (nerve damage) usually fall into in this class.

***Toxicity***

Toxicity, unless qualified otherwise, may be taken to refer to the chemical effects on an organism. Here chemical refers to the material actually taking part in the chemical reaction.

Combined with a prefix such as hepato- (liver), neuro- (nerve), osteo- (bone), thyro- (thyroid) etc. indicates the organ suffering damage, regardless of the origin (chemical or radiological).

***Cumulative Toxicity***

The tendency of some toxic chemicals, for example, heavy metals, to build up in the body. Lead and mercury are the classic examples of this, both materials being excreted relatively slowly under normal circumstances. Most naturally occurring radioactive minerals may be safely assumed to constitute a cumulative toxicity risk.

***Acute Toxicity***

The rapid and severe onset of toxic effects is known as acute toxicity. Most minerals that result in acute toxicity effects do so by dint of their chemical nature rather than any radiological effects.

***Radio-toxicity***

The toxic effects of absorbing radioactive material is always taken to mean the radiation damage caused by the material, as opposed to any purely chemical effects.

## Radiation Safety in The Field

In this chapter we will consider information on collecting radioactive species; these precautions are also appropriate for toxic species.

The three routes of intake of radioactive material into the body are:

<i>Inoculation</i>	passage through the skin, usually as the result of injuries
<i>Inhalation</i>	entry into the lungs either as respirable dust or as vapour
<i>Ingestion</i>	entry into the gut as a result of either eating the material, drinking contaminated fluids or swallowing contaminated phlegm

Each mode of entry carries its own particular risks, and each will be dealt with separately.

If you are in a location that may yield either radioactive or toxic minerals, then it is sensible to ensure that you carry at least some basic hygiene provisions. Wet wipes or baby wipes are invaluable (even if the mud isn't toxic, eating it with your lunch isn't recommended). A first aid kit containing plasters, sterile (isopropyl alcohol, IPA) wipes and a pair of tweezers is highly recommended. A pack of facial tissues, disposable dust mask, safety glasses, surgical examination gloves and a pair of riggers' gloves complete the ensemble. (Total weight, less than 250 grammes or 8 ounces).

### ***Inoculation***

This entry mode is the hardest to prevent. Entry may be through a pre-existing injury or carried into an injury as it occurs.

### **Pre-existing injuries**

Open wounds tend to pick up dust and grit, and should be covered with a plaster or rubber glove prior to commencing work, and should be cleaned thoroughly after work if there is any indication that contamination may have occurred.

### **Fresh injuries**

The simple rule for superficial injuries sustained during field collection is to clean the wound thoroughly soon after it occurs and cover it with a wound dressing, backed up with a rubber glove if on the hand (assuming you are going to continue collecting).

Fresh injuries occur in, essentially, one of three ways: Grazes, Cuts and Shrapnel wounds.

The first of these is commonplace when field collecting, particularly to the knuckles. Grazes tend to drive rock particles into the wound, and are both painful and very difficult to clean properly. These injuries, hard to avoid completely, are prevented in part by wearing suitable leather gloves when doing anything that involves manhandling rock.

The second, Cuts, occur when the skin comes into contact with sharp edges or flakes of rock. Whilst the risk of inclusion of radioactive material into a wound is lessened with a cut, the open wound can still become contaminated subsequently.

*Needlestick* type injuries are characterised by a small puncture wound, often leaving the tip of the rock fragment under the skin.

The final class of injury, shrapnel injury, is caused by flying rock fragments during hammering operations, and occasionally when shifting large, brittle rocks. These flying fragments can impact any exposed skin causing, variously, needlestick and cut type injuries. Smaller, low velocity fragments may stick to the skin and thus carry toxic materials to other parts of the body than the hands.

## ***Inhalation***

Inhalation of dust is the major concern in most cases. Respirable dust falls into two categories ó fine dust which can become lodged in the lungs and coarse dust which becomes trapped in the nose.

For most materials, dust will be removed from the nose and lungs in the normal course of events by the simple expedient of the mucous being transported to the throat and either swallowed or coughed up, or by the nose being blown. Some dusts will inevitably remain deep in the lungs.

It is our objective to prevent the entrapment of these potentially harmful dusts from being allowed into the respiratory tract at all. This is, happily, as easy for the amateur collector as for the professional. The simple expedient of a half-mask disposable respirator (dust mask) will take care of the problem for very little outlay.

These disposable masks should be changed regularly ó whenever they become discoloured or every 4 hours, whichever occurs first.

Inhalation of Gases and vapours, such as Radon, cannot be prevented by a dust mask, and the majority of the radon daughter products are unlikely to be trapped in the weave of a standard dust mask. Radon at extreme concentration also carries the problem of excluding air ó probably not sufficiently to be lethal, but sufficient to cause respiratory distress.

High radon areas should be avoided unless they can be force-ventilated (fans to remove the gas) or unless fresh-air fed equipment is used (such as self-contained breathing apparatus).

## ***Ingestion***

This is largely down to hygiene. A half-mask dust mask will prevent material reaching the gut directly, either through the nose or as dust on the lips (which is invariably licked off).

The following may sound like simplistic prattle, but there is many an intake in industry that was preventable by some simple procedures. Indirect contamination of foodstuffs is very common. Indeed, even the Cornish miners knew to not handle their food because of the risk of arsenic poisoning.

The major route of intake is with foodstuffs. Hands should be cleaned before opening your field lunch-box (wet wipes are ideal), and you should eat away from any sources of dust or other mineral fragments which might settle on your food. Don't forget to wipe your face with a second wet wipe to remove any dust adhering to your skin (it also feels good to get the dirt and grime off!)

Drinks should be taken directly from bottles (don't forget to wipe the neck with a clean tissue before drinking) in order to prevent any intake via dust in your cup.

For obvious reasons, once your hands are clean you shouldn't handle anything but your food until you have finished eating.

***After-Trip***

Once the field trip is complete for the day, you should wash thoroughly, preferably by taking a shower. The aim is to remove any radioactive or toxic residues from your skin and hair. It is a good idea, if possible, to wash field clothes between trips.

Care should be taken to remove any loose residues from clothing, equipment and transport as much as possible.

## Some notes on Field Collecting

Many collectors of minerals prefer to collect their own specimens wherever possible. There are a number of visual clues in the geological environment as to the radioactivity of minerals. Some of these field indicators are valid for specimens obtained other than by self collection.

### *Metamict structure*

Radiation passing through any material does damage to the chemical bonds in that material. In the case of crystalline structures (crystals), this will appear as tiny fractures changing the transparency of the mineral. Ultimately, the crystal may be sufficiently damaged no longer to be a crystal at all, merely powder that was once a crystal.

Metamict materials are typically muddy greens, yellows or browns, and often show uneven or conchoidal fracture where a cleavage would normally be expected.

Two types of metamict structure occur - *auto-metamict* where the crystal suffering damage is the source of the radiation and *para-metamict* where the damage is from an adjacent or included mineral grain. These are also known as *metamict* or *radiation halos*.

Auto-metamict structures arise from the accommodation of Uranium or Thorium in the mineral's crystal structure. Early (pre-Cambrian) zircons are invariably metamict (low-zircon) although the levels of uranium involved are minute. Not all uraniferous minerals necessarily become metamict, for example, Apatite and Xenotime.

Para-metamict structure indicates the contact (or former contact) with uranium minerals.

### *Colour variation*

The presence of a particular ion may alter the colour of a mineral in a characteristic manner, so the presence of uranium or thorium may result in a differently coloured mineral than is the norm.

In addition, the exposure of a species to radiation originating within its structure may result in colour enhancement or colour degradation (bleaching) of the specimen concerned (See *Radio Halos*, below).

### *Fluorescence*

Many radioactive minerals are strongly fluorescent. Most notable is Autunite, with a brilliant green fluorescence under long-wave ultraviolet light which is even visible in daylight. This mineral is a commonplace *indicator mineral*, readily forming thin crusts and tiny patches close to other uranium minerals, and thus indicating the presence of more strongly radioactive deposits.

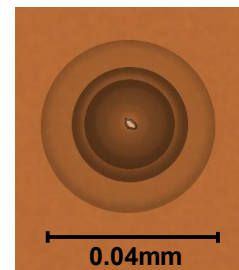
REE minerals are frequently fluorescent of their own nature, so fluorescence is not necessarily an indicator in this case, simply an additional test that may be of use.

## **Radio Halos**

These are zones around a radioactive emitter that have undergone physical and chemical change as a result of radiation damage. These may be short-range (alpha), medium range (beta) or longer range (gamma) damage, the damage being less significant with gamma radiation and more significant with alpha radiation. The effects take several forms.

### ***Pleochroic halos (Radiographic Blackening)***

Some minerals will, under the prolonged influence of alpha particle radiation, undergo gradual change in their structure. Most notable of these is Biotite mica which will develop dark patches around radioactive inclusions, often microscopic crystals of zircon, apatite or sphene. Although these dark patches have a different structure to the remaining biotite, with a less pronounced cleavage, they remain crystalline, and may represent a mixture of the original biotite and a new mineral.



These halos are particularly visible in other micas, although less so than in biotite. Other minerals also exhibit these halos on occasion.

Sourceless halos occur as a result of migration of radon gas through the rock which becomes preferentially adsorbed at particular points in the crystal. The Radon decays, resulting in a small pleochroic halo, simultaneously releasing the adsorption site to capture another radon atom.

Some micas, particularly biotite and muscovite occasionally exhibit interlamellar inclusions which may be result in clearly visible inclusion structures. When these are radioactive the resulting halos overlap, giving an impression similar to that shown to right (approximately actual size).



### ***Radiation bleaching***

The chemical changes caused by the passage of radiation may cause coloured ions to become non-coloured ions; strongly coloured ions may become less strongly coloured ions or there may be destruction of colour centres. Thus a corona of bleached (or pale-coloured) mineral or rock surrounds a radioactive mineral.

### ***Colour enhancement***

In a process quite the opposite to bleaching, some minerals will develop colour in the presence of nuclear radiations. Amethyst is probably the best known example of this (yellowish iron-rich quartz becomes a rich purple colour). Feldspars often become red (but don't confuse this with iron-rich feldspars, such as are found on Dartmoor, UK).

Whilst the presence of amethyst (and, indeed, some smoky quartzes, coloured topaz etc.) indicate radiation in their past, they may not indicate radiation in the present day. However, coloured halos surrounding included or superficial deposits of other minerals are a sure sign of radioactive minerals.

Many minerals which have become impregnated with organic chemicals (asphalts) will display a colour change. An excellent example of this is Blue John, a particular deep-blue banded fluorite from Derbyshire, UK. Here the royal-blue colour is due to the presence of asphalt in the crystal structure.

Typical enhancements in colour:

Mineral	Colour change from:	to:
Quartz	White/clear Pinkish	Smoky grey or purple Purple or red
Feldspar	White	Red pale Blue/Green
Fluorite	White/clear	Dark purple or deep blue
Asphalts	Yellow/brown /black etc.	Any strong colour is possible ó rich reds, deep blues, greens and purples have been noted.
Micas	White - Brown	Deepening of colour, eventually to brown and black.
Topaz	White	Strong yellows and orange, cinnamon brown etc. Blue
Beryl	Greenish	Strong blue
Spodumene	Pale, almost white	Pink
Elbaite	Pink	Intense red
Garnet	Deep red	Violet
Halite	Pale	Blue, Red etc.
Opaque Minerals		No colour enhancement generally seen
Iron III minerals	Red	Green (Iron II)

*Chemistry of Colour Changes*

Many colour changes are dependant on the presence of particular ions in the crystal lattice, and the presence of different ions in two crystals of the same mineral will result in different colour changes.

Quartz: Iron results in the purple of Amethyst (normally pale yellow)  
 Aluminium produces the grey or smoky quartz (normally clear)  
 Aluminium, Boron and Iron(III) have been cited as the origin of colour in Rose Quartz, which colour may be enhanced by radiation.

Asphalt: The colours are caused by: Sulphur, Nitrogen, Metal Ions, Oxygen, Ring Structures, Double/Triple Bonds etc.

Feldspar: Red ó is caused by the presence of Iron  
 ó probably as nanocrystals of Hematite  
 Blue/Green ó is caused by lead,  
 ó and is seen in its extreme form in Amazonite.

Red Iron(III) may, under some circumstances, be converted to the pale green Iron(II) under the influence of radiation. On the other hand, it would appear that in granites, the radiation may cause the deposition of red Iron(III) compounds.

## ***Geological Environment***

### ***Known Locations***

The biggest, most obvious and *most often overlooked* clue as to radioactivity is simply the location. Minerals from known sources of radioactive minerals are more likely to be radioactive.

### ***Known Associations***

The next most often overlooked clue as to radioactivity is that of known associations. Some minerals are often associated with each other. If a radioactive mineral is often found in association with a non-radioactive one, then it is more likely to have at least a small amount of radioactive content.

### ***Facies (Host rock)***

Pegmatites, coarse-grained intrusive rocks, are excellent hunting grounds for minerals, as are their associated granites. Rarer basic and intermediate chemistries occasionally occur in pegmatites.

Whilst the rare-earth elements and such metals as uranium and thorium abound in all igneous rocks, it is in pegmatites that they are most often concentrated to the point of being significant components of mineral species.

Similarly, some areas and structures tend to concentrate any radioactive elements that happen to be present. The pre-Cambrian structures at Oklo, Gabon are the classic example, where the uranium concentration actually rose high enough to create natural fission reactors deep underground.

### ***Clastic Halos***

These are halos of cracks radiating from a mineral grain or pocket. They are often associated with coloured halos (bleaching, colour enhancement or colour change which will vary between minerals).

These cracks may occur along grain boundaries or across grains in the rock, depending upon the condition of the host rock.

Where a void exists, the interior will often have a dark brown or black colour, with a somewhat burned appearance.

### ***Faults, Joints and Cracks***

Where radioactive minerals are known to occur, uranium minerals are often concentrated along faults, joints and cracks in the host rock, especially where the rock is relatively impermeable. Uranium is often marked by the presence of gummite, a resinous yellow, orange, brown and black secondary deposit which is often accompanied by powdery yellow minerals.

### ***Resinous Surface***

Uranium minerals, in particular, tend to migrate. Pitchblende and Gummite are frequently present and will form a typical migration structure on surfaces. The mixture of minerals appears as a burned resin coating on the rock, brownish to black; it gives the inside of a crack or fracture a slick surface, often with a yellowish dusting (gummite).

## ***Field Examples***

### **Littleham Cove Uranium-Vanadium concretions.**

These post-deposition concretions are common in the Littleham mudstones, in Littleham Cove in Devon, UK.

These are nodules of indeterminate composition that exhibit a low level of radioactivity. They appear as unimpressive grey lumps, breaking up easily. The nodules are located within bright red, ferruginous mudstones, and are invariably located within an aureole of pale mudstone.

While they have long been regarded as examples of long-term radiation bleaching, they are now believed to represent a combination of syn-depositional bacterial action and purely chemical, post depositional leaching.

### **Foggintor Quarry - Uranium-Schorl veins.**

Meldon Vale, on the north-west part of Dartmoor, UK is a well-known site for uranium minerals. To the west, there lies Foggintor Quarry. Here the uranium is deposited in a small number of boron-rich veins comprising quartz-schorl with traces of other minerals. These are associated with numerous smaller veins, some of which also contain elevated levels of Uranium minerals.

Many of the veins are surrounded by aureoles of somewhat altered feldspars, as shown to right. Whilst always accompanying uraniferous veins, many non-uraniferous veins are accompanied by these reddish aureoles ó the red also being associated also with the greisenisation of the granites.



**Part IV: A key to the radiological considerations of mineralogical species**

**Arrangement of Part IV**

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## Mineralogical Radiation Protection Classes

For the sake of simplicity, Radioactive minerals will be divided arbitrarily into five categories.

Category	Hazard Description
0	Non-radioactive. Conventional safety considerations only are necessary.
0x	Of sufficiently low activity to be classed as non-radioactive for all safety purposes. $A_{sp} < 35 \text{ Bq/g}$
I	Radioactivity is of academic interest, but has no safety implications, except in bulk quantities. $A_{sp} > 35 \text{ Bq/g}$ $D_{sp} > 0.0004 \text{ Sv/hr @ 1m}$
II	Radioactivity is sufficient to warrant consideration for all but the smallest specimens. $A_{sp} > 250 \text{ Bq/g}$ $D_{sp} > 0.04 \text{ Sv/hr @ 1m}$
III	Radioactivity is sufficient to require safety considerations for most specimens. $A_{sp} > 25 \text{ kBq/g}$ $D_{sp} > 0.40 \text{ Sv/hr @ 1m}$
IV	Radioactivity is sufficient to require significant safety planning for all but the smallest specimens. Major considerations for storage must be made $A_{sp} > 1.0 \text{ MBq/g}$ $D_{sp} > 4.00 \text{ Sv/hr @ 1m}$
X	Radioactivity is sufficient to require major safety planning for all but the smallest specimens. Extreme storage considerations must be made $A_{sp} > 10.0 \text{ MBq/g}$ $D_{sp} > 40.0 \text{ Sv/hr @ 1m}$

## ***Description of Classes***

There follows a brief summary of the radiological requirements of each mineral category.

Please note that the amount of material held impacts heavily on the storage requirements for mineral specimens. For example, a gram of Radian Barite (Class IV), whilst requiring additional handling precautions, will have roughly the same storage requirements of, say, 2kg Uraninite (Class III), and a 10mg micro specimen of Uraninite (Class III) will have the same storage and handling requirements as an equivalently sized micro of any non-radioactive mineral; it will, however, require airing when the box is opened.

### **Class 0 and 0x minerals**

#### ***Class 0 minerals***

- Only basic hygiene measures required.
  - ó Wash hands after handling
  - ó No eating or drinking etc. when handling.
  - ó Keep away from food-preparation areas.

#### ***Class 0x minerals***

- Only basic safety measures required.
  - ó Wash hands after handling
  - ó No eating or drinking etc. when handling.
  - ó Keep away from food-preparation areas.
- Ventilate storage boxes/bags etc. before handling.
- Radioactive specimens may interfere with radioassay if adjacent to assay system.
  - ó Will introduce additional peaks if placed close to gamma spectrometry systems.

### Class I minerals

- More than basic safety measures required.
  - ó Wash hands after handling
  - ó No eating or drinking etc. when handling.
  - ó Keep away from food-preparation areas.
  - ó Use of gloves and/or forceps recommended.
- Thoroughly ventilate storage boxes/bags etc. before handling.
- Ensure that the room in which these materials are stored has proper ventilation.  
i.e. not a draught-proofed room.
- Some thought to shielding and ventilation may be needed if large quantities (over 50kg) are stored.
- The presence of small amounts of this material may interfere with radioassay if stored within, say, 1m.

## **Class II minerals**

- Significantly more than basic safety measures required.
  - ó Wash hands after handling
  - ó No eating or drinking etc. when handling.
  - ó Keep away from food-preparation areas.
  - ó Use of gloves and/or forceps is highly recommended.
- Handling of larger (hand/cabinet) specimens will require some consideration to dose reduction.
- Storage of these specimens may introduce elevated radiation and radon levels into a dwelling.
- The presence of this material will interfere with radioassay if stored within, say, 2m.
- The close proximity of this material will fog photographic film.

**Class III minerals**

- Significantly more than basic safety measures required.
  - ó Wash hands after handling
  - ó No eating or drinking etc. when handling.
  - ó Keep away from food-preparation areas.
  - ó Use of gloves and/or forceps should be preferred.
- Radiochemical hygiene precautions are required. All class III minerals bear risk of injury if absorbed into the body. (Cancer, acute toxicity and chronic heavy-metal toxicity risks)
- Children, pets and women of childbearing capacity should not be exposed to the radiation fields surrounding these materials for prolonged periods. (Cancer risk and, in the case of women, possibility of birth defects.)
- Handling of specimens will require significant consideration to dose reduction. Special handling procedures should be preferred in all instances.
- Storage of these materials will introduce elevated radiation and radon levels into a dwelling. Larger specimens and stock material should be maintained in shielded storage, preferably with outside ventilation.
- Display of these materials should preferably be behind a few millimetres of lead-acrylic or lead-glass ó clear, shielded boxes designed for radio immuno-assay reagents are excellent for this purpose.
- Consideration should be given to limiting the amount of this material held where appropriate.
- The presence of this material will significantly interfere with radioassay if stored within a few metres.
- The proximity of this material will rapidly fog photographic film.
- Special precautions should be taken when disposing of significant amounts of these materials.

**Class IV and Class X minerals**

- Significantly more than basic safety measures required.
  - ó Wash hands after handling
  - ó No eating or drinking etc. when handling.
  - ó Keep away from food-preparation areas.
  - ó Use of gloves and/or forceps should be seen as a basic requirement.
- Radiochemical hygiene precautions are absolutely necessary. All class IV and above minerals bear risk of severe injury if absorbed into the body. (Cancer, acute radio-toxicity and heavy-metal toxicity risks)
- Children, pets and women of childbearing capacity should not be exposed to the radiation fields surrounding these materials. (Severe cancer risk and, in the case of women, likelihood of birth defects.)
- Handling of specimens will require major consideration to dose reduction. Special handling procedures should be observed. Personal shielding (lead panels and lead-acrylic face shields) should be used when working with these materials.
- Storage of these materials will introduce highly elevated radiation and radon levels into a dwelling. Specimens should be maintained in shielded and externally-ventilated storage. Cabinet specimens should be small, and kept behind at least a few centimetres of lead-acrylic or lead-glass ó clear, shielded boxes designed for radio immuno-assay reagents are excellent for this purpose.
- The amount of this class of material owned should be strictly limited.
- The presence of this material will severely interfere with radioassay if stored within several metres, and will impair all readings taken if stored within, say, 2m.
- The proximity of this material can fog photographic film within hours or minutes.
- Special precautions should be taken for the disposal of these materials.

## List of Class III, Class IV and Class X minerals

*NB: These lists are subject to change*

### Class IV and Class X Minerals ( $A_{sp} > 1\text{MBq/g}$ )

Radian Barite

Hokutolite

### Class III Minerals ( $A_{sp} > 25\text{kBq/g}$ )

Abernathyite	Derriksite	Meta-ankoleite
Agrinierite	Dewindtite	Meta-autunite
Albrechtschraufite	Dumontite	Metacalcouranoite
Althupite	Fontanite	Metahaiweeite
Andersonite	Fourmarierite	Metaheinrichite
Arapovite	Francevillite	Metakahlerite
Arsenuranospathite	Francoisite-(Nd)	Metakirchheimerite
Arsenuranylite	Fritzscheite	Metalodevite
Ashanite	Furongite	Metanovacekite
Asselbornite	Grimselite	Metaschoepite
Astrocyanite-(Ce)	Guilleminite	Metastudtite
Autunite	Haiweeite	Metatorbernite
Bassetite	Hallimondite	Metatyuyamunite
Bauranoite	Haynesite	Meta-uranocircite
Bayleyite	Heinrichite	Meta-uranopilite
Becquerelite	Holfertite	Meta-uranospinitite
Bergenite	Hugelite	Metavandendriesscheite
Betafite	Huttonite	Metavanmeersscheite
Bijvoetite-(Y)	Ianthinite	Metavanuralite
Billietite	IMA2004-001	Metazellerite
Blatonite	IMA2004-022	Metazeunerite
Boltwoodite	IMA2004-029	Moctezumite
Brannerite	Irginite	Moluranite
Calciouranoite	Ishikawaite	Moreauite
Calcurmolite	Jachymovite	Mourite
Carnotite	Johannite	Mundite
Cejkaite	Joliotite	Nickel-zippeite
Chadwickite	Kahlerite	Ningyoite
Chernikovite	Kamitugaite	Novacekite
Clarkeite	Kamotoite-(Y)	Orthobrannerite
Cliffordite	Kasolite	Orthowalpurgite
Cobalt-zippeite	Kivuite	Oswaldpeetersite
Coconinoite	Larisaite	Oursinite
Coffinite	Lehnerite	Paraschoepite
Compreignacite	Lepersonnite-(Gd)	Parsonsite
Cousinite	Lermontovite	Petscheckite
Coutinhoite	Liandratite	Phosphowalpurgite
Cuprosklodowskite	Liebigite	Phosphuranylite
Curienite	Magnesium-zippeite	Phuralumite
Curite	Marecottite	Phurcalite
Deliensite	Margaritasite	Piretite
Deloryite	Marthozite	Protasite
Demismaeckerite	Masuyite	Przhevalskite

Pseudo-autunite	Sodium-uranospinite	Uranosilite
Pseudojohannite	Sodium-zippeite	Uranospathite
Rabbittite	Spriggite	Uranosphaerite
Rabejacite	Strelkinite	Uranospinite
Rameauite	Studtite	Uranotungstite
Ranunculite	Swamboite	Uranpyrochlore
Rauvite	Swartzite	Ursilite
Renardite	Tengchongite	Uvanite
Richetite	Thorianite	Vandenbrandeite
Romanite	Thorite	Vandendriesscheite
Roubaultite	Thorogummite	Vanmeersscheite
Rutherfordine	Thorutite	Vanuralite
Sabugalite	Threadgoldite	Vanuranylite
Saleeite	Torbernite	Vochtenite
Samarskite-(Y)	Triangulite	Voglite
Sayrite	Tristramite	Vyacheslavite
Schmitterite	Trogerite	Walpurgite
Schoepite	Tyuyamunite	Weeksite
Schrockingerite	Ulrichite	Widenmannite
Sedovite	Umohoite	Wolsendorfite
Seelite-1	Upalite	Wyartite
Seelite-2	Uramphite	Xiangjiangite
Sengierite	Uranocalcarite	Yingjiangite
Shabaite-(Nd)	Uraninite	Yttrocolumbite-(Y)
Sharpite	Uranmicrolite	Zellerite
Sklodowskite	Uranocircite	Zeunerite
Soddyite	Uranophane	Zinc-zippeite
Sodium meta-autunite	Uranophane-beta	Zippeite
Sodium-autunite	Uranopilite	Znucalite
Sodium-boltwoodite	Uranopolycrase	

## An extensive guide to Radioactive Minerals.

This section comprises a list of minerals which may be reasonably expected to be radioactive. Many REE (Rare Earth Element) minerals have up to a few percent of the REE replaced by Thorium, or more rarely, Uranium.

The minerals are described by name, ideal (published) chemical formula and also by high and low radioactivity formulae. The expected activity and dose-rate from one gram of the mineral is given for each of the two non-ideal formulae, as well as the nominal radiation class for the mineral.

For technical reasons the high and low radioactivity formulae are not shown in classical chemical format, they contain non-integer proportions of elements which indicate the levels of substitution where appropriate; they are expressed in linear form without any subscripting and without structures, ionisation or oxidation states indicated.

For example 6 Three mineral varieties have the following entries:

**Mineral:** **Thorianite**  
**Formula:** ThO<sub>2</sub>  
 High Activity Formula: ThO<sub>2</sub>  
 Specific Activity: 39371.1781 Bq  
 Specific Dose @1m: 0.4990 Sv/hr Class III  
 Low Activity Formula:  
 Specific Activity:  
 Specific Dose @1m:

**Mineral:** **Barite var. Radian Barite**  
**Formula:** (Ba,Ra)SO<sub>4</sub>  
 High Activity Formula: (Ba0.995,Ra0.005)SO<sub>4</sub>  
 Specific Activity: 17910849.0509 Bq  
 Specific Dose @1m: 249.8975 Sv/hr Class IV  
 Low Activity Formula: (Ba0.999,Ra0.001)SO<sub>4</sub>  
 Specific Activity: 3582714.1869 Bq  
 Specific Dose @1m: 49.9871 Sv/hr Class IV

**Mineral:** **Barite var. Hokutolite**  
**Formula:** (Ba,Pb,Ra)SO<sub>4</sub>  
 High Activity Formula: (Ba0.95,Pb0.049,Ra0.001)SO<sub>4</sub>  
 Specific Activity: 3529980.9659 Bq  
 Specific Dose @1m: 49.2513 Sv/hr Class IV  
 Low Activity Formula: (Ba0.95,Pb0.04999,Ra0.00001)SO<sub>4</sub>  
 Specific Activity: 353000.6180 Bq  
 Specific Dose @1m: 0.4925 Sv/hr Class III

As can be seen, Thorianite has a formula for radioactivity calculations identical to its published formula. Both Hokutolite and Radian Barite have actual formulae differing from the standard formula. Some minerals have additional elements shown in the radioactive forms where the usually documented formula may contain no radioactive elements.

No other data is given, this being readily available from any number of sources.

### ***Interpretation of the Mineral Data***

The figures stated in the table of mineral data are per kilogram of mineral (specific activity and specific dose). The dose rate is quoted at a distance of one metre from the specimen.

In order to calculate doses and activities, the mass of each active mineral species needs to be known or estimated. The specific activity or dose for each radioactive mineral present is multiplied by the mass of that mineral (in kilograms). This will give the total activity or dose arising from that mineral.

If the individual activities or doses are added, then this will give a total for the entire specimen. Thus, for an example specimen 6

Mineral Name	Mass	High Activity	Low Activity	High Dose @1m	Low Dose @1m	Dose Hazard Class	
						High	Low
	Grammes	Bq	Bq	uSv/hr	uSv/hr		
<b>Exemplar-01</b>	27						
Uranophane	2.3	256771.1915	256771.1915	3.2156	3.2156	III	III
Autunite	0.5	44004.7240	44004.7240	0.5511	0.5511	III	III
Hügelite	0.1	8698.4595	8698.4595	0.1089	0.1089	II	II
Kahlerite	0.1	7818.4150	7818.4150	0.0979	0.0979	II	II
Aeschnyite-(Nd)	10	6427.9025	0.0000	0.0815	0.0000	II	0
	<b>13</b>	<b>323720.6925</b>	<b>317292.7900</b>	<b>4.0550</b>	<b>3.9735</b>	<b>IV</b>	<b>III</b>

The Dose Hazard class is calculated as follows:

- |   |   |
|---|---|
| If the dose is exactly 0.0000 Sv/hr                   | then the hazard class is <b>Class O</b>   |
| If the dose is below 0.004 Sv/hr                      | then the hazard class is <b>Class Ox</b>  |
| If the dose is above 0.004 Sv/hr and below 0.04 Sv/hr | then the hazard class is <b>Class I</b>   |
| If the dose is above 0.04 Sv/hr and below 0.40 Sv/hr  | then the hazard class is <b>Class II</b>  |
| If the dose is above 0.40 Sv/hr and below 4.00 Sv/hr  | then the hazard class is <b>Class III</b> |
| If the dose is above 4.00 Sv/hr and below 40.0 Sv/hr  | then the hazard class is <b>Class IV</b>  |
| If the dose is above 40.0 Sv/hr                       | then the hazard class is <b>Class X</b>   |

If the dose at 1m exceeds 4.00 Sv/hr, then there is need for serious consideration of special precautions for the handling and storage of the material. Lead lined storage boxes are advised.

If the dose at 1m exceeds 40 Sv/hr, then significant lead and concrete shielding is highly recommended, and you should consider the advisability of reducing your radioactive mineral holdings.

## Alphabetical Index of Radioactive Minerals

**Note:** These figures are for guidance only. The absence or presence of a mineral species or variety from this list should not be taken to indicate that there is no possibility of any particular specimen of that mineral being radioactive; the activity and dose figures given are for indication only and may not be completely representative of the levels measured in the presence of any particular specimen of that mineral.

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## **Section under Construction**

**Minerals Aa – Az**

**Minerals Ba – Bz**

**Minerals Ca – Cz**

**Minerals Da – Dz**

**Minerals Ea – Ez**

**Minerals Fa – Fz**

**Minerals Ga – Gz**

**Minerals Ha – Hz**

**Minerals Ia – Iz**

**Minerals Ja – Jz**

**Minerals Ka – Kz**

**Minerals La – Lz**

**Minerals Ma – Mz**

**Minerals Na – Nz**

**Minerals Oa – Oz**

**Minerals Pa – Pz**

**Minerals Qa – Qz**

**Minerals Ra – Rz**

**Minerals Sa – Sz**

**Minerals Ta – Tz**

**Minerals Ua – Uz**

**Minerals Va – Vz**

**Minerals Wa – Wz**

**Minerals Xa – Xz**

**Minerals Ya – Yz**

**Minerals Za – Zz**

**Numerical and minerals  $\alpha$  –  $\omega$**

## **Unnamed Species**

## **A note on the specification of unnamed species**

Unnamed species fall into three categories: IMA Approved species; published species Awaiting IMA Approval; Published but insufficiently characterised to be submitted for approval.

Unnamed IMA Approved species are identified by a temporary name in the format

**IMA2001-732**

where the first four digits represent the year of approval

and the digits following the hyphen represent a serial number during that year

Unnamed species awaiting IMA approval are identified by a temporary name in the format

**UM2001-732-SO:FeMn**

where the first four digits represent the year of approval

and the digits following the first hyphen represent a serial number during that year

and the essential chemistry is stated in the format Anions : Cations

Unnamed and largely uncharacterised minerals (including well-defined mineral mixtures etc. from particular locations) are identified by a description in the following format

**Unnamed (Fe-Mn-Sulphate)**

Strictly speaking there should follow further information such as the author publishing the supposed mineral And/or the location at which it was found and/or the publication where the material was first reported. Thus, the above becomes

**Unnamed (Fe-Mn-Sulphate) RowanA:NonesuchCove**

or

**Unnamed (Fe-Mn-Sulphate) RowanA-MineralsJournal-35:06**

**Unnamed (Fe-Mn-Sulphate) MineralsJournal#315-NonesuchCove**

Note that the journal issue number is either the issue number from the commencement of publication (prefixed with a #) or the volume and part numbers, separated by a colon.