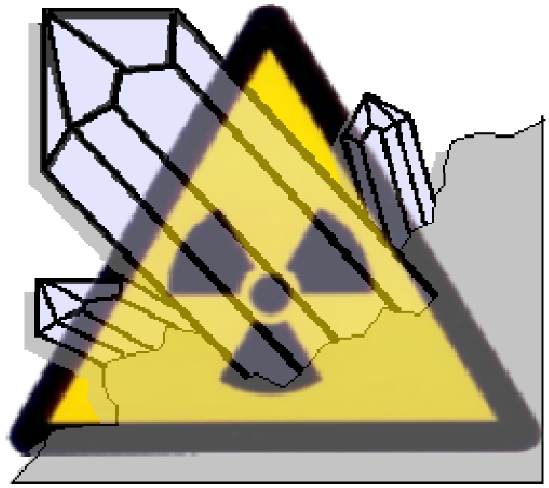
Undoing the demonisation of radioactive minerals



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Abstract— ***This is a very brief introduction to radiation safety. The major part covers the health implications of radiation exposure. The section on Radiation Safety covers the simple measures needed to remain protected.***

Keywords— ***Health Physics, Radioactive Minerals, Radiation Safety***

TABLE OF CONTENTS

I. INTRODUCTION

For many years the press have bombarded the population with the idea that (nuclear) radiation and radioactive materials are the quintessential evil of our time. What becomes lost in this is the fact that high energy radiation pervades our universe and that everything is slightly radioactive, including all living things. This discussion will attempt to put the matter of naturally radioactive materials back into perspective.

The first part of the article will discuss the ALARP (as Low As Reasonably Practicable) principle and means of minimising radiation exposure while pursuing the collecting of radioactive minerals as a part of your hobby.

The later part of this article describes what radiation is and how it interacts with matter - specifically, living tissue - at the single emission scale. There follows a discussion of the effect of radiation on the human organism and how natural radioactive materials relate to radiation exposure in everyday life.

II. RADIATION SAFETY

A. ALARP - Minimising Exposure

The introduction of the Radioactive Substances Act (1974) introduced an entirely novel concept to British law - the concept of that which is *Reasonably Practicable*.

In this, the whole concept of radiation exposure was treated as inevitable, but in order to minimise the risk, the idea was to reduce the exposure to *As Low As Reasonably Practicable*.

The term *reasonably practicable* means that all means of limiting radiation dose should be used provided that they do not impair the process and are not ruinously expensive.

The simplest way to achieve *ALARP* is to simply avoid doing anything with radiation or radioactive materials. Given that this is an article about ***radioactive minerals***, that is not reasonable, but there are precautions which *are* reasonable.

B. Time, Distance, Activity & Shielding

There are four aspects of radiation exposure that may be controlled in order to minimise risk:

1) Time

The amount of time you are exposed to radiation affects the risk: Double the time of exposure equals double the radiation absorbed which in turn equals double the risk.

2) Distance

The distance from a source of radiation affects the risk: Doubling the distance **quarters** the radiation absorbed (*inverse-square law*) - conversely halving the distance quadruples the absorbed radiation.

3) Activity

The amount of radioactive substance affects the risk: Double the amount of material doubles the risk.

4) Shielding

Shielding generally reduces the amount of radiation which is absorbed. The thickness and material of the shielding affects its efficiency in reducing radiation fields. Formal shielding calculations take into account both the shielding material and the radiations being shielded.

5) Ventilation

When dealing with uranium and thorium bearing materials, there is an additional factor which comes into play - *radon gas*. Radon is a radioactive noble gas which decays rapidly into a series of other radioactive and toxic elements before becoming lead. Radon exposure is mitigated by the simple expedient of providing ventilation. Bearing in mind that Radon is a gas that is denser than air, this means that basements should have forced ventilation (fans to the outside).

C. Routes of Exposure

There are four routes of exposure to radiation, one external and three internal.

1) External

Radiation that impinges on you from the environment. For most, this is the only significant exposure. ***Ideally*** this **will** be the only form of exposure.

2) Internal - By Ingestion

Radiation exposure, primarily of the mouth and gut, to radioactive material which is swallowed.

3) Internal - By Inocculation

Radiation exposure to an entry site and subsequent exposure of the whole body by skin absorption or by contaminants being carried into the body through a puncture wound.

4) Internal - By Inhalation

Radiation exposure, primarily of the respiratory tract, through inhalation of radioactive gases and respirable dusts and vapours.

D. Specifics

In every case, the aim is to reduce the internal exposure of the individual to as close to zero as our environment will allow.

- Wear work gloves
- Wear a dust mask when appropriate
- Avoiding eating or drinking

The external radiation dose is able to be minimised by limiting how long you are in close contact with radioactive materials, keeping your distance from them where possible, and keeping them in a suitable container (away from children and animals).

1) Hygiene

An overall or lab coat should be worn when working with radioactive specimens. Surgical examination gloves are the minimum protective equipment for handling them.

- Work surfaces should be wiped with a damp paper towel or disposable cloth, at least.
- After use, examination gloves should be removed (turning them inside-out in the process) and disposed of.
- Lab coat etc. should be washed frequently.
- On completion of work, the hands should be washed thoroughly with soap and water, and the face should be washed carefully.
- Equipment may be cleaned using disposable wet wipes.

2) Handling

Significant precautions in handling radioactive minerals:

- Wear surgical examination gloves in order to prevent contamination of the hands.
- Wear eye/face/respiratory protection while performing specimen preparation work.
- Work on a disposable surface at all times (newspaper, Kraft paper, kitchen towel etc.).
- Radioactive minerals should always be placed in a tray for transport .

3) Special precautions for close-up examination.

- Never place a radioactive mineral close to your naked eye.
- Always use a magnifier (which provides shielding), and always close your off-eye (in order to shield that

eye). Beware of contamination on the eyepiece, if appropriate.

- Never lick minerals suspected of being radioactive (you shouldn't lick minerals in any case).
- Never sniff radioactive minerals - especially metamict minerals.
- Do not use domestic equipment with radioactive minerals - ensure that you have tools and equipment designated solely for mineralogical use.

4) Susceptible Individuals

Children and the unborn foetus are particularly at risk, *unnecessary* radiation dose should be avoided in both cases until at least 18 years of age.

5) Storage

Radioactive minerals may be stored anywhere away from high-traffic areas of the home, and must be stored away from any foodstuffs, food preparation areas and washing areas.

Wooden boxes placed inside a steel filing cabinet are most highly recommended - the wood absorbs the beta radiations, the distance and (thin) steel will reduce the gamma intensity. For large collections of radioactive minerals, a lead "foil" lining (1 or 2 layers of lead flashing) on the **outside** of the wooden boxes and their lids is recommended.

6) Display

Highly radioactive minerals should be displayed from the rear of a display cabinet, which should be placed against an outside or a brick/concrete etc. internal wall. A layer of lead flashing on the outside of the rear of the cabinet is recommended.

The distance and the glass/perspex front of the cabinet will provide sufficient protection from all but the largest specimens.

Specimens of Radian Barite and very large Uraninites etc. will require special measures, as these give rise to extreme levels of radiation.

Display cabinets should be either vented to the outside or, if unvented, left open to breathe for about 20 minutes before handling any specimen (with surgical gloves, at least).

- Never store/display radioactive minerals where you sleep.
- Never store/display radioactive minerals where you eat or prepare food.
- Never store/display radioactive minerals close to where you sit or otherwise remain for extended periods.

7) Amounts of Material

Specimens on display should be as small as reasonably possible, and should not be presented in large numbers.

If you wish to display large numbers of radioactive specimens, then a suitable room or outbuilding should be used away from residential areas of the home.

*- How much is a **reasonable** quantity of radioactive minerals?*

This is a question similar to many others concerning mineral collection. Ask yourelf what the specimen adds to your collection. If you have a plate that shows a fine bed of some crystals or shows a relationship between a group of minerals, that is reasonable. If it is a massive chunk of anonymous brown radioactive '*stuff*' then you may wish to consider reducing the size of the piece (or just displaying a small chunk of it).

As a guideline and given that most uranium minerals are found only as thin, crystalline crusts, no more than about 250g of radioactive minerals should be on display in any living area of the home; anything over 500g of radioactive mineral should be considered too much for domestic display.

Anything over that amount should be stored outside of the living area of your home. Possession of over 5kg of radioactive mineral should lead you to consider more advanced shielding and storage in your lab/workshop area.

8) Waste Disposal

Waste generated in the handling of radioactive minerals is of sufficiently low level to be legally and safely disposed of when mixed with domestic (landfill) waste. Small amounts of radioactive mineral offcuts, while not legally radioactive, should be dispersed within your domestic (landfill) waste.

III. What is Radiation?

Radiation is, literally, any energetic emission that travels through space from a particular source. This includes sound, water spray from a nozzle, light, radio waves etc.

The kinds of radiation that concern us, however, are the high energy emissions from such sources as The Sun, X-ray machines, nuclear reactors and radioactive materials. Since the topic in question concerns radioactive minerals, only these will be considered although the same principles apply for any source of high energy radiations.

These high energy radiations individually carry negligible amounts of energy on a human scale, but on a molecular or cellular scale, the energies are enormous and can cause massive amounts of damage - either by ionising the material or by causing mechanical damage.

A. Where does the radiation come from?

The energetic emissions that are significant originate in the nuclei of unstable atoms. In an attempt to become energetically stable, the nucleus will eject particles of matter and a photon or two of gamma radiation. Although other decay modes exist, the only significant ones in mineralogy are Alpha decay and Beta-Gamma decay.

Alpha emissions are particles identical to the helium nucleus. They travel at relativistic speeds, and may both ionise matter they interact with, or produce ballistic damage by knocking light atoms from their places in molecules. They may also, in some cases, cause neutrons to be displaced from certain materials. An alpha decay is occasionally accompanied by the emission of a gamma photon.

Beta decay involves a neutron losing a tiny amount of mass in the form of a relativistic electron, thus changing the neutron into a proton. Beta particles typically leave dense ion-trails through air by displacing electrons from air molecules, and finally come to rest, becoming simple electrons. (There is actually a second particle emitted in the opposite direction, an anti-neutrino, but since these do not interact with matter very often, they can be safely ignored).

At some small time after the emission of a beta particle, there will always be at least one gamma photon emitted. These gamma photons will always be at a particular energy (or choice of energies) depending on the nucleus which has decayed. The photon(s) may be anything from visible light (1 electron-Volt) up to many mega electron-Volts (MeV). The only gamma radiations of concern are those beyond the Ultra Violet part of the spectrum, which are both readily detectable and commonplace. Below that level, the radiation is lost in the general illumination of the world at large.

Gamma photons only interact weakly with matter, but they do interact, and in a number of complex ways - all of which cause ionisation damage to that matter.

B. What does the radiation do?

The energetic emissions that are significant to this article originate in the nuclei of naturally radioactive elements, specifically those in the decay chains of Uranium and Thorium. To a lesser extent, marginally radioactive elements also exist in nature, including *vanadium*, ***organic*** *carbon*, ***atmospheric*** *hydrogen* and *potassium*.

Alpha radiation, the most densely ionising radiation under consideration, is an extremely large particle and as such travels very short distances in air - the **most** energetic alpha radiation travels about a metre in air. Generally a few centimetres of air, thin paper or human epidermis (the dead part of your skin) will shield you from alpha radiation.

If an alpha particle encounters a living cell, it will penetrate the cell, causing ionisation damage as well as mechanical damage to that cell. Generally, the damage will kill the cell in question.

Beta radiation is also strongly ionising. Being lighter (and smaller), beta radiation penetrates matter more deeply than alpha radiation. It is stopped by a few millimetres of aluminium, a few metres of air, less than a millimetre of lead and about 7mm of skin tissue, acrylic plastic or wood.

When the skin is exposed to beta radiation, the particles will barely penetrate the epidermis, and enter the dermis, causing damage to the living tissue beneath. The resulting burn from **extended** exposure (known as a *beta erythema*) is indistinguishable from a sunburn.

If beta radiation is allowed to impinge upon dense materials (e.g. lead, barium, gold, tungsten), then the kinetic energy is given up as a combination of heat (as in less dense materials) and photons - which are often energetic enough to be classed as x-rays - these secondary x-rays are known as *bremstrahlung radiation*.

Gamma radiation (also **X-rays** and **ultra-violet light**) interact relatively weakly with matter, although they penetrate deeply. The strength of this interaction is a function of wavelength.

Ultra-violet penetrates to roughly the same depth of tissue as beta radiation, though it is shielded by any opaque material. Ionisation is weak by comparison with X-rays.

Soft radiations penetrate matter more deeply, passing through most materials but with high attenuation.

Hard radiations penetrate indefinite amounts of matter with variable attenuation.

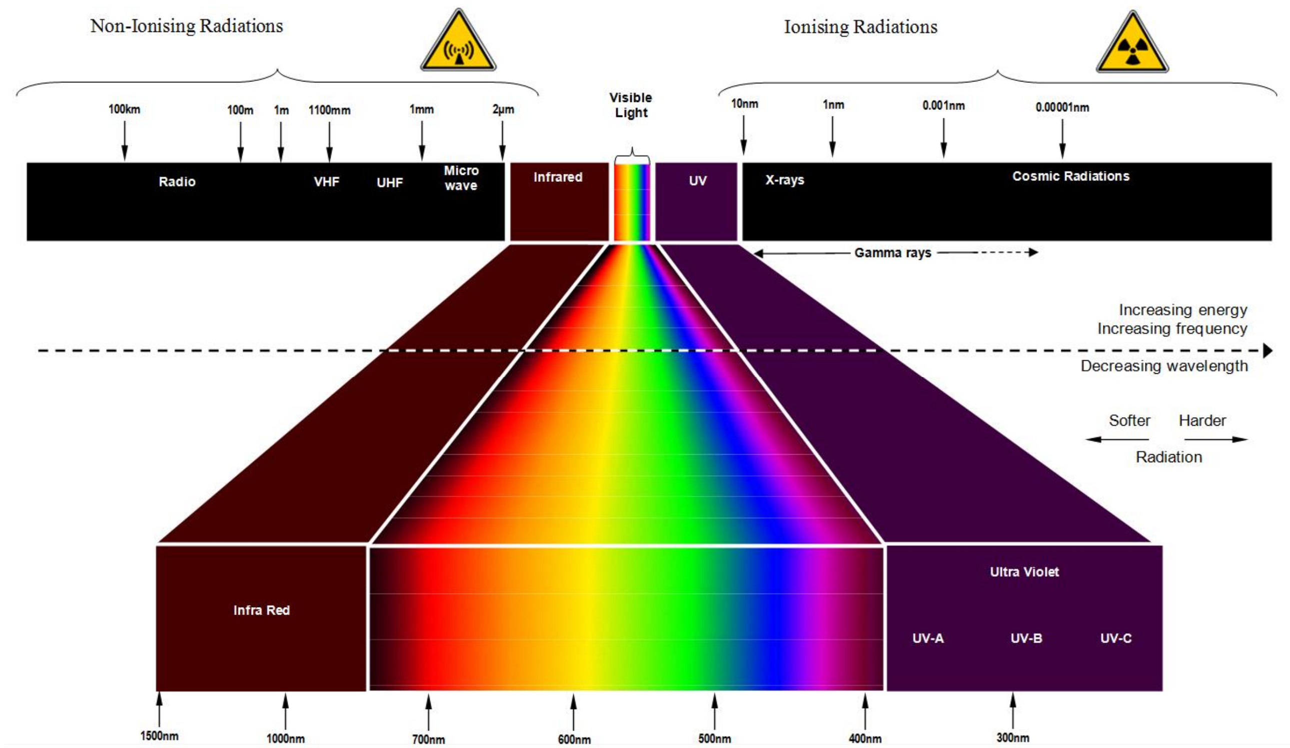

Fig. 1. The electromagnetic radiation spectrum - a continuum of wavelengths and energies.

As gamma radiation passes through matter, it interacts by exciting bound electrons in that matter - they may have sufficient energy to ionise the atom, the ejected electron then causing secondary ionisations, or the electron may simply be raised to a higher energy state, which on return to its rest energy, will release a photon (*photo-electric effect*).

If the gamma photon has sufficient energy, it may be converted by close proximity to an atomic nucleus into an electron-positron pair which will, after a short time, annihilate, releasing two photons of gamma radiation (*pair production*).

X-rays are occasionally present in nature when an intense beta radiation source is shielded by a dense material, resulting in the creation of x-rays. This is often found in the case of large uranium deposits.

IV. Interaction with Living Organisms

A. Effects Within the Organism

When ionising radiation interacts with a cell within the living tissue of an organism, there are four possible outcomes:

- There is no change.
- A minor and insignificant change occurs to a cell's chemistry.
- The cell dies immediately.
- A significant, non-lethal change occurs to the cell

Only the third and fourth of these possibilities are significant - if sufficient cells are killed in an area, then this is an acute exposure, and the organism experiences a radiation burn. Most pale-skinned humans experience this at least once in their lives - sunburn being an acute radiation burn.

Significant modification to cells will occur at either the cellular or the genetic level. Cellular level changes will result in the cell eventually being replaced. Genetic changes will result in a modification to the operation of the cell. This gives rise to *potential* chronic repercussions from radiation exposure.

Generally, changes to the genetic make up of a cell will result in it either undergoing DNA repair, or it will be identified as an alien cell by the organism's immune system, resulting in the death of the cell. Occasionally, due either to a suppressed immune response, or a change that doesn't trigger the immune response, the cell will continue to operate in its new role. Rarely, the damage is to the means for the cell to regulate division - the cell will begin to divide indefinitely. These cell clusters usually prompt an immune response - if they do not, then the resultant cell body (neoplasia) will become a tumour (usual), whether benign or cancerous (less usual).

B. Generational Effects

While it is recognised that radiation exposure to the unborn foetus **may** have a ***teratogenic*** effect resulting in mild to severe birth abnormalities, there is insufficient evidence to indicate that there is any ***mutational*** implication of exposure.

So far, only first generation and second generation effects have been seen, where second generation effects are entirely ascribable to first generation *in utero* exposure.

Third generation effects have, so far, not been observed in humans.

The dose required to produce teratogenic abnormalities are, like all of these things, quite high.

C. Susceptible individuals

Statistically, radiation exposure has an increased chance of causing long-term damage in tissues undergoing rapid cell division. This means the lining of the gut in everyone, and likewise sites of injury (cuts, operative wounds, broken bones etc.)

Children and the unborn foetus are particularly at risk, *unnecessary* and *excessive* radiation dose should be avoided in both cases until at least 18 years of age.

V. Exposure and Probability

When considering the effects of radiation on an organism, we have to know three things about the radiation: quality, intensity and duration of exposure.

The **quality factor** (Q) of the radiation is a measure of how much damage is done by each unit of radiation.

The **intensity** (i) of the radiation determines how rapidly it does that damage.

The **duration of exposure** (t) determines how much damage is done by that radiation.

The product of these three yields a value (D), the **radiation dose** (absorbed dose equivalent, in Sieverts)

i – $D = Qit$

The radiation absorbed dose equivalent per unit time (D/t) is the **dose rate**. Dose rate is altogether a more useful unit when considering radiation safety.

Quality factors for the radiation types encountered in nature:

Radiation type	Quality Factor
X-, gamma, or beta radiation	1
Alpha particles	20

When a radiation interacts with living tissue, the damage caused is likely to be:

Consequence	Probability†
Functional damage	
- leading to immediate cell death	90%
- leading to eventual cell death	9%
Genetic damage	
- leading to DNA repair	0.99%
- leading to cell removal	0.0099%
- leading to potential benign neoplasia	0.00009%
- leading to potential non-benign neoplasia	0.00001%

À Very approximate values given for scale only.

From this, it is clear that the probability of long-term effects (neoplasia - tumour) from each radiation interaction is extremely small. Additionally, in a healthy individual virtually all neoplastic development is dealt with by the immune system.

It is possible to infer, even from this simplistic statistic, that:

- The likelihood of both long- and short-term health issues is related to the amount of radiation encountered.
- The likelihood of long-term health issues from even moderate exposure to radiation is small.

It is also understood that long-term health effects typically manifest only after twelve to forty years after exposure, depending upon the exposure conditions. Generally speaking, there is only a marginal risk of radiation mediated disease when moderate exposures are experienced. The risk from sun exposure is significantly higher than exposure to nuclear radiation in most people's lives.

VI. Environmental Radiation

Our world is radioactive, and we are radioactive, too - even before the discovery of radioactivity, uranium, radium and so forth, humans were exposed to nuclear radiation.

Radioactive carbon and radioactive hydrogen are generated in the upper atmosphere by dint of solar radiation - this becomes incorporated into plants and, ultimately, us. Likewise, natural potassium (a vital part of our bodies) includes a long-lived radioactive isotope (potassium-40). The list goes on.

Some places, usually granite uplands or sedimentary deposits originating from the granite, are significantly radioactive. Uranium and Thorium bearing minerals are known from many locations across the world. In the UK, the Cornubian Granites are well known for their uranium deposits. What is less well known is that the extensive Permo-Triassic red beds in the south-west of England are derived from the granite, and are riddled with uranium-vanadium minerals. Given how radioactive these places are, no one even considers moving away from them.

The fact is that the human organism, indeed all life on Earth, is adapted to tolerate a certain amount of radiation damage. The mechanisms for repair of damage sites extends from the smallest monocellular organism to humans and plants; the mechanisms to repair DNA damage goes further, in that even the simplest monocellular life is able to repair the majority of DNA damage. This repair mechanism is the reason that radiation sterilisation requires such enormous radiation exposure in order to ensure that every contaminating cell is destroyed.

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References

[1] Alysson Rowan, óHere be Dragonsj The Care and Feeding of Radioactive Mineral Species (Feb 2017)ô. [Online]. Available: https://www.academia.edu/31501150/Here_be_Dragons_The_Care_and_Feeding_of_Radioactive_Mineral_Species_Feb_2017_. [Accessed: 16-May-2018].

[2] Alysson Rowan, óHere be Dragonsj The Care and Feeding of Radioactive Mineral Species - Mineral Data (Feb 2017)ô. [Online]. Available: https://www.academia.edu/31507928/Here_be_Dragons_The_Care_and_Feeding_of_Radioactive_Mineral_Species_-_Mineral_Data_Feb_2017_. [Accessed: 16-May-2018].

[3] H. Cember and T. E. Johnson, *Introduction to health physics*. New York: McGraw-Hill Medical, 2009.

[4] H. Semat and J. R. Albright, *Introduction to atomic and nuclear physics*, 5. ed. (Reprint). London: Chapman & Hall, 1978.

[5] H. Semat and J. R. Albright, *Introduction to atomic and nuclear physics*, 5. ed. (Reprint). London: Chapman & Hall, 1978.

[6] óGuidance on the scope of and exemptions from the radioactive substances legislation in the UKô, p. 114.

[7] HSE, óHealth & Safety Executive - Radiation Protection Websiteô. [Online]. Available: http://www.hse.gov.uk/radiation/index.htm. [Accessed: 16-May-2018].

[8] HSE, óHealth & Safety Executive - Introduction to Radiationô. [Online]. Available: http://www.hse.gov.uk/toolbox/radiations.htm. [Accessed: 16-May-2018].

Essential Glossary

Electron-Volt (eV)
A unit of energy used in nuclear physics; the energy gained by an electron accelerated across a potential difference of 1 volt.

In utero
Lit: In the uterus; an unborn foetus.

Metamict
A mineral that undergoes mechanical damage through its own radioactivity.

Mutagenic
Lit: Causes Change; Permanent, inheritable changes to the racial DNA of offspring.

Neoplasm
Lit: New Organ; A tumor or other abnormal cell growth.

Relativistic
Some object that travels at close to the speed of light.

Teratogenic
Lit: Causes Monster; causes birth defects.