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Is Natural Radiation Good for You?

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Lecture notes (for use with accompanying presentation)

Slide 1 : Title

Slide 2 : Radiation Based Health Products - Examples

It isn’t my intention to argue that natural radiation is good for you - although in the earlier half of this century there was a widespread belief that it was. The idea almost certainly came from the long established belief that bathing in natural mineral water springs is beneficial to health; when it was discovered that the waters in many of the most popular springs were radioactive, containing quite high concentrations of dissolved radon, it was assumed that this newly discovered property was the source of the perceived health benefits.

The Revigorator was one of many products that exploited the newly discovered phenomenon of radioactivity by presenting it as a natural remedy. It was glazed internally with a mixture of uranium and radium salts; water stored in it overnight built up a concentration of dissolved radioactive radon gas as it was emitted from the radium in the glaze.

The Radioactive compress made by Radiochema of Jachymov, was guaranteed to contain 0.1 milligrams of radium by no less than the Institut du Radium at the Laboratoire Curie in Paris, and recommended as a remedy for arthritis and related conditions

The Food and Drug Administration in the US started to take action against this sort of product in the 1930s, and by the 1960s their production had ceased altogether. It’s now universally accepted that their use was much more likely to be harmful than beneficial.

Consumer products containing radioactivity continue to be made in Japan - this fridge deodoriser contained significant quantities of thorium - given that its half-life is billions of years the claim to be ‘endless’ is quite reasonable. This product was banned from distribution in the US by the NRC in the 1980s.

Slide 3 : Radium Palace

Moreover, it is still possible to book health breaks at many spas that actively prompt the radioactivity in their waters. The Radium Palace in Jachymov, Czechslovakia is a good example.

Here one can enjoy many treatments, including bathing in the radon rich waters and taking special radon bath treatments. The spa proudly advertises the source of its waters as being deep underground springs in the Svornorst silver and uranium mine - for those interested in the numbers, radon concentrations vary from 5,000 to 20,000 Bq per litre.

There is no consistent approach to regulation of this type of facility in Europe. Radiation exposures of spa workers may be limited by national regulations, but in many countries doctors are free to prescribe the treatment for their patients.
There is a good deal of anecdotal evidence for benefits in relation to rheumatism and other inflammatory conditions (which would be unlikely to convince NICE in the UK); however most radiation protection scientists would agree that if any such benefits existed at all they would be offset by a marked increase in the risk of lung cancer and other malignant diseases.

So I don't want to argue that exposure from natural radiation is beneficial. Rather, I want to explore the comparison between exposure to natural radiation and radiation exposure that arises from man-made sources.

Slide 4 : Average radiation exposure of the UK population

Comparisons like this are often shown to point out that natural radioactivity is a far greater source of exposure to the population than is any man-made source. In fact, the largest man-made source on average is exposure during medical procedures, although this is distributed vary un-evenly within the population as much of the total comes from large radiotherapy doses to a relatively small number of individuals. By comparison the contribution from 'disposals' - discharges of radioactivity into the environment from nuclear installations - appears quite negligible.

One obvious objection to this comparison is that it averages out the effects on people living close to nuclear sites and other man-made sources of exposure.

Slide 5 : Radiation exposure of high rate fish and shellfish consumers on the Cumbrian coast

However, even if we look at those people most exposed to radioactivity from Sellafield's discharges, natural sources still dominate. And it may come as a surprise that radioactivity still in the environment from processing phosphate rocks - which are rich in natural radioactivity - at the Marchon works appears just as important as the discharges from Sellafield.

The releases of radioactivity from any new build nuclear reactors would be many times smaller than those from Sellafield. So from this sort of comparison it’s hard to understand how there can be any sort of argument or concern about the health risks of nuclear power, unless we argue that man-made radioactivity is somehow much more harmful than the natural kind.

But these arguments do continue. The reason can be traced to the nature of the unit I have used for these comparisons - the radiation dose expressed in the Sieverts - without explaining what the units actually are.

Before I do try to explain that, I need to explain a little more about what radioactivity is and how it arises naturally.

Slide 6 : Radioactive decay

Radioactivity is a process originating in the cores of atoms - their nuclei. These nuclei may be thought of as containing particles with a positive electric charge - protons - and particles of similar mass but no electric charge, which are neutrons. Together these are called ‘nucleons’.

As like electrical charges repel you might expect the nucleus to be unstable and fly apart immediately.

If this were the case, matter as we know it couldn’t exist, and neither could we. Fortunately Nature has provided another force, the strong nuclear force, which is attractive between nucleons at very short distances. This balances the repulsive electrical force and allows atoms to exist.

However the balance is quite fine, and in some atoms the configuration of the nucleus is unstable. Stability can be restored in a number of ways - most commonly by converting a proton to a neutron and emitting an electron at considerable velocity (beta particle) or alternatively emitting a combination of two protons and two neutrons (alpha particle).

In either of these processes the re-arranged nucleus may have some excess energy (rather like a bell ringing after it has been struck) - this can be emitted as high energy electromagnetic radiation (gamma rays).
The beta particles, alpha particles and gamma rays are collectively described as ‘ionising radiation’ for reasons that will become clear shortly.

Slide 7 : Nuclear stability

Nuclear configurations in which the number of neutrons is a little higher than the number of protons provide us with the 79 stable chemical elements, from hydrogen to lead, from which our physical world is constructed.

All nuclei heavier than lead are unstable and so radioactive; nuclei on one side or the other of the area of stability are also radioactive. We call atoms with unstable nuclei ‘radionuclides’; by one or another of the radioactive decay processes they are transformed eventually into one of the stable elements

But where do all of these different elements and nuclides, whether radioactive or not, come from - and why should there be any radioactivity naturally present in the world today - surely any unstable radionuclides should have re-arranged themselves long ago, and become stable?

Slide 8 : Origin of the elements

The answer to the first part of the question is that all the elements from which Planet Earth and ourselves are made were assembled by nuclear fusion reactions in stars.

By about 1 second after the Big Bang, matter in the Universe consisted only of the simplest atoms - mostly hydrogen, with about 20% helium. Over the next billion years, gravity caused the hydrogen and helium to clump together and form the first stars and galaxies.

Within stars, there is another exquisite balancing of the forces of nature. The gravity from the enormous mass of material in a star causes the atomic nuclei to be squeezed together very closely, overcoming the electromagnetic forces which otherwise would keep them apart.

This allows a sequence of nuclear fusion reactions to start - initially, hydrogen nuclei fusing together to form helium. This releases huge amounts of energy as electromagnetic radiation; the outward pressure of this balances the gravitational force and keeps the reaction running steadily so that the hydrogen-helium reaction can power a star for billions of years, which again is rather fortunate for us.

Eventually, the hydrogen fuel runs out; gravity squeezes the star harder and ignites a further series of reactions, until (if the star is massive enough, at more than 10 times the mass of our Sun) the core consists largely of iron. These sequential reactions proceed ever faster - the final silicon to iron step occurring in a single day.

But fusing iron nuclei doesn’t liberate energy, but consumes it. At this point the star is rather like Wile E Coyote when runs off a cliff and realises there’s nothing to hold him up. Gravity wins and a catastrophic collapse occurs - a supernova.

A supernova isn’t really an explosion, as most of the star’s mass implodes to form a neutron star or a black hole. But the outer regions of the star are blown away, and intense neutron radiation provides the energy to build up heavier elements from the iron formed by fusion.

This material now contains all of the elements that we are familiar with, together with a wide range of radioactive isotopes; initially the material ejected from the supernova is highly radioactive.

Over time the radioactivity from the more unstable radionuclides decays away, and more stable nuclides are formed. Over billions of years, the dust becomes incorporated into a newly forming solar system - like ours was five billion years ago - and this new solar system can have planets and, just possibly, life.

So, quite literally, the planet Earth and all life on it, including ourselves, is made of stardust. Less poetically, you could say it is made from long cooled radioactive waste.

Slide 9 : Primordial radionuclides

Some of the radionuclides formed in the supernova are <u>nearly</u> stable - that is to say, rearrangements of their nuclei only occur rather infrequently, so that it takes a long time for them to transmute into a stable form. Another way of saying this is that they have a 'long half-life' - this being the time taken for half of the original unstable atoms to be transformed.

So these radionuclides are still present on the Earth, and in us, as the last radioactive residues of the supernova from which our solar system was formed.

Its interesting to see that potassium-40 and uranium-235 have half-lives significantly shorter than the five billion year age of the Earth, so that the amounts of these present would have been much higher in the earlier geological eras.

[POTASSIUM-40 DEMONSTRATION]

Potassium is a very common element. About 1 part in 10,000 by weight of all potassium is the radioactive isotope potassium-40 (the main stable isotopes are potassium-39 and potassium-41). Although this proportion is very small, potassium in bulk is appreciably radioactive.

Here, we have 12 kg of potassium sulphate supplied as a fertiliser - containing about 5 kg of potassium. The gamma radiation from it is clearly discernible above the general background level - as the last traces of energy from a star that exploded more than 5 billion years ago.

Our bodies typically contain around 150 grams of potassium - this gives rise to the oft used analogy that sleeping with a partner, rather than alone, increases your exposure to radiation - but it clearly isn't a very large effect.

Slide 10 : Uranium and thorium decay series

The radioactive properties of uranium and thorium are particularly important. Looking again at the nuclear stability chart, and concentrating on the top right part of the diagram, we can see that uranium-238 is a long way away from the nearest stable nuclides - which are isotopes of lead and bismuth.

So uranium-238 can’t transform into stable nuclide in a single step. It proceeds through a series of intermediate nuclides, which are also radioactive, to ultimately reach stability as the stable isotope lead-206. The intermediates are called ‘daughter radionuclides’; although any of them have short radioactive half-lives they are continually being produced be radioactive decays of uranium-238 and the other daughters higher up the chain.

Uranium-235 decays through a similar series, reaching stability as lead-207, as does thorium-232 to reach lead-208.

Slide 11Uranium-238 decay series
Looking at the uranium-238 series in more detail, one daughter is of particular importance. Radon-222 emits alpha radiation and has a short half-life of only about 3 days, but the element radon is a ‘noble’ gas - one that is chemically very stable. So once radon-222 has been produced by radioactive decay of its parent, it readily escapes from the solid matrix in which it was formed - be that rocks, soil, water or even building materials - and disperses in the air.

Once it does escape, it quickly produces a series of short lived alpha and beta emitting isotopes of polonium, bismuth and lead as its daughters. These radon daughters rapidly become attached to microscopic particles of airborne dust, forming an aerosol of radioactive particles that can be inhaled and deposited in the lungs.

Concentrations of radon ad its daughters in the air depend on the rate at which radon is released into the air, and the rate at which it is dispersed away. So concentrations inside buildings tend to be higher than those in the outside air.

The presence of radon daughters in air is usually quite easy to demonstrate with very simple equipment.

[RADON DEMONSTRATION]

Slide 12 : Radon demonstration

Earlier this afternoon, we set up in the Rosehill barn a small air sampler pulling air through a glass fibre filter. This allows radon gas to pass through, but collects the radon daughters which are present on airborne particles.
[VIDEOCLIP]

As the daughters decay quite quickly, the sampler has been running throughout and Jordi has now kindly retrieved the filter. Using a very simple radiation detector - used for contamination surveys on nuclear plants - the alpha radiation from the filter is clearly detectable. (We are seeing just over 10 counts per second, which on a very rough calibrations suggests the levels in the barn are close to the national average of 20 Bq m-3 222Rn)

I can also demonstrate an important property of alpha radiation - although the individual alpha particles have a high energy they are absorbed very quickly, being stopped by a single sheet of paper. So all there energy has been deposited in a short distance - we say alpha particles are ‘high linear energy transfer’, or ‘high LET’, radiation.

Radon concentrations vary very markedly across the UK - the same demonstration in a further education college in Cornwall produces a much more marked response. [VIDEO CLIP]. Here the concentration is at about the UK action level for remediation, about 200 Bq m-3 Rn222. [Other parts of this video clip show an embarrassingly young version of myself and have been omitted for reasons of personal vanity]

Slide 13 : Cosmogenic radionuclides

Radioactivity is also being produced continually in the upper atmosphere from cosmic rays. These are very energetic particles emitted both from the sun but, more predominantly, from other more distant sources in the Galaxy. They comprise mostly protons and alpha particles, with a small proportion of heavier atomic nuclei and very high energy electrons. The typical energies of these particles are about 10,000 times higher than the ionising radiation we have discussed so far; the most energetic particles are well above the capability of the Large Hadron Collider to produce, so we shouldn’t worry too much about being swallowed by a black hole when it’s switched on again.

On striking the atmosphere these particles produce a cascade of nuclear reactions - these result in secondary radiation reaching ground level, and contributing to the radiation background. In addition a number of relatively short lived radionuclides are formed from interactions with target atoms in the atmosphere. The most important of these are tritium, beryllium 7, carbon 14, and sodium-22; the production rates of tritium and carbon-14 greatly exceed the total global emissions of these radionuclides from the nuclear industry (although of course concentrations in the vicinity of a nuclear site may be dominated by the local emission).

Slide 14 : Radiation doses from natural sources

Natural radioactivity results in everyone being exposed to ionising radiation. Exposure may be from a source of ionising radiation outside the body - as is the case for cosmic rays and gamma radiation from primordial radionuclides in rocks and soil. Alternatively it may be from radioactivity taken into the body - as is the case for inhaled radon daughters, from potassium 40 in the body and from the intake of other naturally occurring radionuclides in food.

This slide shows the relative importance of the exposures, expressed in microSieverts. The importance of radon inhalation is evident, and as we have seen the magnitude varies from the average very markedly according to local geology and other conditions.

However, I’m presenting results in microSieverts again without explaining what they are. So I must now try to do this; the Sievert (or microSievert) is a unit defined so as to allow the relative health risks of different kinds of radiation exposure to be compared. Its definition is key to my original question of whether the comparison of natural and man-made sources of radiation exposure are misleading or not.

Slide 15 : Absorbed radiation dose - the Gray

The basic unit of radiation dose is the Gray, named after Louis Harold Gray, a British hospital physicist who worked at the Mount Vernon Hospital, London and laid all the basic foundations for the science of radiation biology. In particular he developed the concept of Relative Biological Effectiveness, of which more in a moment.

The Gray is a simple measure of energy deposition per unit mass, expressed in SI units.

All physical scientists will be comfortable with a unit definition like this. In principle it is capable of being measured directly by standardised methods - unlike some of the other units in radiological protection.

Slide 16 : So what dose do you get from drinking a cup of coffee?

It's possible to demonstrate something important about the Gray by a simple experiment - drinking a cup of coffee.

Anyone who remembers experiments with calorimeters in school physics lessons will be able to follow the calculation that drinking a cup of coffee transfers nearly 15,000 Joules of thermal energy to the body. Averaged over my body weight, that amounts to 180 Joules per kilogram, or an energy 'dose' of 180 Grays.

But if I'd received that energy dose from ionising radiation, I'd be facing some very serious health consequences.

Sometimes experiments with a null result are very informative - in this case the everyday experience that drinking a cup of coffee doesn't kill you outright shows clearly that there is something very special about the energy deposited in living tissue by ionising radiation, that is very different from thermal energy.

Slide 17 : Size matters - in the quantum world, at least

To explain the special property of energy deposition by ionising radiation, we need to consider quantum theory very briefly.

Einstein did, of course, receive the Nobel Prize. He was awarded it in 1921, not for this equation (E=mc2), but for a rather less well known equation (E=hv) related to his 1905 paper on the photoelectric effect.

Einstein was able to interpret other published research on the emission of electrons from surfaces illuminated by visible and ultraviolet light. He showed that the energy of light is not continuous, or infinitely divisible, but is composed of discrete, very small, units called 'quanta'. The size of these quanta is directly related to the frequency (inversely related to the wavelength) by a universal constant known as Plank's constant.

Ironically, having established the basic tenet of quantum theory Einstein became uncomfortable with the deeper philosophical ramifications of the theory and spent the last part of his life trying to disprove them.

Slide 18 : The electromagnetic spectrum

As the frequency of electromagnetic radiation increase (wavelength decreases) the size of the quanta increase to the point where they correspond to the energy required to disrupt chemical bonds between atoms - this is the boundary between visible and ultraviolet light. At higher frequencies still, they correspond to the energy required to strip electrons out of atoms and molecules completely, leaving electrically charged 'ions'. This is the boundary between ultraviolet light and X-rays, the lowest energy form of ionising radiation proper.

Deposition of energy in this way is biologically very disruptive and is the basis of the 'special' properties of ionising radiation.

Slide 19 : Energy deposition, DNA and LET

For low level exposure to ionising radiation, the health effect of greatest concern in the potential for an increased risk of cancer following exposure. Damage to DNA is a key part of the mechanism leading to cancer, and the density of ionisation events relative to the dimensions of DNA influences the outcome considerably.

The density of ionisation events from passage of gamma ray photons or beta particles through tissue is quite sparse on the scale of the DNA molecule. (This illustration grossly oversimplifies the structure of ionisation tracks in tissue).

We have seen that alpha particles exhibit high linear energy transfer - this translates into a high density of ionisation events on the scale of DNA.

Damage to DNA from beta or gamma radiation is only likely to result in the breakage of one strand of the helix; repair mechanisms in the cell can deal with this relatively easily.

However alpha particles are much more likely to break both strands, leaving damage that is repaired much less effectively.
In consequence, for the same amount of energy deposited alpha radiation can do much more damage to DNA than can beta or gamma radiation

Slide 20 : Equivalent dose - the Sievert

Our next unit is the Sievert, named after Rolf Maximillian Sievert - a medical physicist who headed the Department of Radiation Physics at the Karolinska Institute in Stockholm and was chairman of both the International Commission on

Radiological Protection and the United Nations Scientific Committee on the Effects of Atomic Radiation.

The Sievert is the unit of equivalent dose, in which the absorbed dose in Grays is multiplied by a factor representing the ‘relative biological effectiveness’. These factors are known as ‘radiation weighting factors’ and you’ll see from the values that they represent rather ‘broad brush’ figures. They are chosen largely on the basis of experiments on cell cultures, examining the relative effectiveness of the different radiation types in producing a variety of biological damage types, or ‘end points’; judgements are made as to the figure that would best represent the relative effectiveness in terms of carcinogenesis.

I argue that a from a purist point of view the Sievert can’t be seen as a true physical unit. There is no standardised method of measuring it directly, and there is certainly not a standard Sievert sitting alongside the standard kilogram at the International Bureau of Weights and Measures.

The Sievert is the result of an assessment that roughly represents the risk of cancer following the deposition of ionisation energy in tissue.

Slide 21 : Effective dose (also the Sievert)

Rather confusingly, the Sievert is also used as a measure of another radiation dose quantity - that of effective dose.

The idea of effective dose comes from the extensive epidemiological study that has been carried out, largely by the US and Japan, on the survivors of the Hiroshima and Nagasaki atomic bomb attacks.

The survivors were subjected to a large and fairly uniform absorbed dose throughout their bodies, from a combination of gamma rays and neutrons. Long term epidemiological follow-up shows that the subsequent incidence of cancer differs between organs; weighting factors (again rather broad brush in nature) are derived to represent this difference. The idea here is that if the radiation dose is not spread uniformly throughout the body, use of these weighting factors will result in a figure that represents the cancer risk resulting from that amount of radiation dose delivered uniformly to the whole body.
This is ‘Equivalent dose’

Slide 22 : Effective dose (also the Sievert)

[summary of the definition of effective dose]

Effective Dose (Sv) = Sum over all organs and radiation types of:
Absorbed dose (Gy)
x radiation weighting factor
x tissue weighting factor

We are now, of course, even further away from something that could be considered a physical unit - it is a dose quantity that results from a form of assessment, applying factors that are in part based on judgement.

Slide 23 : Estimating effective dose

We must now consider how we estimate (NOT measure) the effective dose. I'll concentrate on radiation exposure in the environment - to both natural and anthropogenic sources.

If the radiation is from a source outside the body - such as cosmic rays, or gamma rays from rocks and soil - there are many sensitive instruments that can detect the incident flux of ionising radiation and, if necessary, establish the nature and energy of the radiation. From that, calculating the resulting deposition of energy within the body (and its distribution) relies on well established physics and there isn't much argument about the method of estimation.

If the source of radiation is inside the body - following inhalation of radioactivity, or its ingestion in food - things become much more difficult.

Slide 24 : Internal dosimetry

For the estimation of effective dose from internal emitters, we have to simplify the real human anatomy, physiology and pharmacokinetics into a mathematical or 'biokinetic' model that can be solved to establish the distribution, retention and clearance of radionuclides in important organs following inhalation or ingestion of radioactivity.]

For most purposes, these models represent as best they can the average, or typical, behaviour of radionuclides in the body; although differences with age are modelled variability between individuals is only rarely considered.
Anyone who has done this sort of work will know that the reliability of the results depends critically on how the model is structured and how all the model parameters are specified.

From the results of the time dependent concentrations of radionuclides in the various organs, equivalent doses to each body organ, and hence effective dose, can be calculated.

Almost all assessments of effective dose rely on 'look up' tables of effective dose per unit intake of each radionuclide, developed by the ICRP from their biokinetic models. Fortunately we don't have to solve these models each time we do an assessment!

Slide 25 : Lung dosimetry

The ICRP's models must, in some cases, reflect the distribution of radionuclides within organs, as well as between them. The model of the respiratory tract is a good example.

Inhaled radioactive particles are deposited initially into the mucus layer that lines the airways. Many of the particles will be cleared from the lung with mucus by the action of the small hairs (cilia) on the airway surface; soluble radionuclides may be dissolved and transferred to the bloodstream; and a small proportion of the particles may be engulfed by macrophages and transferred into the underlying airway tissue. It is thought that most lung cancers originate from the cells at the base of the inner lining of the airway - the epithelium. So it is necessary to estimate the dose to these cells - the 'target cells' - quite specifically.

For radiation sources external to the body, this isn't a problem as the dose is delivered quite uniformly and the 'target cells' receive the same dose as the rest of the lung tissue.

This isn't the case for internally deposited radioactivity. As the distance between the mucus layer (or the underlying mucosal tissues) and the basal cells of the epithelium is comparable to the range of alpha particles in tissue, the model must reflect the distribution of any particles carrying alpha emitters quite specifically.

It's worth noting that, for long lived alpha emitters like plutonium, the equivalent dose to the basal cells for insoluble particles depends heavily on assumptions about the retention of a small proportion of the deposited material in the deeper tissue of the airways; of all the parameters in the model these are the ones that have least support from experimental data.

Slide 26 : Estimating intakes

So if we can estimate intakes of radioactivity, we can estimate effective dose from internal radioactivity.

In order to do this, we need to think of the pathways by which radioactivity may be transferred to humans, and the locations at which this may happen. Radioactivity concentrations in air, water and food can be determined by sampling and analysis or, if we are thinking about the future impact of a new nuclear facility, by use of more mathematical models.

Radionuclide intakes will clearly be dependent on individual habits, such as the quantities of different foodstuffs consumed and their source. Effort therefore tends to be focussed on groups that likely to be most highly exposed - 'critical groups' or, in ICRP's latest terminology, 'representative persons for the purpose of dose assessment'.

Slide 27 : Steps in assessing effective dose

The steps I have described lead to the evaluation of a quantity - effective dose - that is inevitably subject to uncertainty and which is not, even in principle, possible to confirm by direct measurement.

This applies, of course, to the estimation of effective dose from both natural and anthropogenic sources.

The ICRP and the UK's Health Protection Agency emphasise that this system of dosimetry is intended to provide a standard framework to show compliance with dose limits in radiation protection - it is not intended to support a scientific assessment of radiation risk.

Slide 28 : Radiation exposure of high rate fish and shellfish consumers on the Cumbrian coast

So, if we look again at the comparison between effective dose from natural sources and those from Sellafield's discharges, we must reflect that both estimates are, in reality, subject to significant uncertainty. For the comparison to be invalid the estimates must be affected in different directions by uncertainty, and by quite a substantial amount.

It's possible to imagine ways in which this could happen - and also to think of counter-arguments as to why it's unlikely. This uncertainty in the estimate of internal radiation dose lies at the heart of the debate about low level radiation risks.

So are there any more direct ways of looking at this?

Slide 29 : More direct evidence?

[Summary of bullet points]

- Direct measurements of radioactivity in exposed individuals?
- *Possible (and used) in some aspects of occupational exposure, only of very limited use in environmental exposure*
- Look for evidence of ill health in exposed populations - epidemiology?
- *An important check - but particularly for environmental exposure, can be a rather blunt instrument…..*

So, with only a small risk of prejudicing a future professorial lecture, I do need to say a few words about epidemiology.

Slide 30 : Epidemiology - Hiroshima and Nagasaki

Much of our knowledge about radiation effects on humans comes from the epidemiological study of Hiroshima and Nagasaki survivors.

This is a very well constructed study, and the increase of cancer mortality with increasing radiation dose is regarded as a very strong result.

But if we look at the results in a different way, we see that the difference between observed and expected mortality is not that dramatic. It emphasises a key point that in epidemiology determining the number of cases of disease in a population is the easy part - the reliability of the study depends critically on how you estimate how many would have been expected, in the absence of the effect you are trying to study.

For this reason epidemiological studies - or perhaps quasi-studies - are not infrequently abused by both sides of the low level radiation debate.

Slide 31 : Is natural radiation entirely harmless?

As radon is one of the largest and most variable sources of natural radiation exposure, it is perhaps the most likely source to produce an observable epidemiological result. However as the main expected outcome from radon exposure is an increase in lung cancer risk, the effects of smoking need to be taken very carefully into account.

In a large recent study that combined the data from thirteen studies across Europe, a clear association was found between residential exposure to radon and the risk of lung cancer - even when homes with the highest concentrations were excluded from the analysis. The implied risks per unit of radon are reasonably consistent with those observed at much higher concentrations in occupationally exposed miners.

A cost-benefit study published this month in the BMJ uses these results to conclude that 1100 lung cancer deaths a year in the UK are related to radon exposure in the home - although the risks are still very much higher for smokers than for non-smokers.

These study also concluded that whilst basic measures to mitigate radon concentrations in new homes would be cost effective even if applied nationally, intervention in existing homes with high concentrations would not be. In radiation protection attention is often focussed on limiting the highest exposures - so the study may be of interest to those interested in optimisation in the nuclear industry.

A second very recent paper concludes that natural radiation could account for a significant proportion of childhood leukaemia - but this is not as yet backed up by epidemiological observation.

Slide 32 : Conclusions

[Summary of conclusions]

- Natural radiation isn’t good for you - but think of it as a risk we’ve learned to live with

- Comparisons between natural and anthropogenic radiation exposure are based on good science, but also on judgements and assumptions that are hard to test rigorously
- The public and political sensitivities surrounding nuclear power guarantee that there will be continued debate on low level radiation risks but…..
- Entrenched and polarised positions produce a climate inimical to good scientific judgement (or any other sort of judgement) and consequently bad decision making

With radiation we at least know what we don’t know.