No Immediate Danger, Prognosis for a Radioactive Earth, by Dr. Rosalie Bertell
The Book Publishing Company -- Summertown, Tennessee 38483
ISBN 0-913990-25-2
pages 15-63.

P A R T   O N E

The Problem:

Nuclear Radiation and its Biological Effects

The Seed

The future of humankind is present today within the bodies of living people, animals and plants -- the whole seedbearing biosphere. This living biosystem which we take so much for granted has evolved slowly into a relatively stable dynamic equilibrium, with predictable interactions between plants and animals, between microscopic and macroscopic life, between environmental pollutants and human health. Changes in the environment disturb this balance in two ways: first, by altering the carefully evolved seed by randomly damaging it, and second, by altering the habitat, i.e. food, climate or environment, to which the seed and/or organism has been adapted, making life for future generations more difficult or even impossible.

Although examples of maladaptation in nature and resulting species extinction abound, our focus here is on human seed, the sperm and ovum, and the effect on it and on the human habitat resulting from increasing ionising radiation in the environment.

The increased use of radioactive materials, which is a direct outgrowth of the current military and energy policies of the developed world, provides an opportunity for gauging what priority these countries give to the health and well-being of individual citizens, and for gauging governments' understanding of the tension between individual and national survival. The first indicator of underlying national priorities is the precision or lack of precision with which health effects are predicted, and the thoroughness with which an audit is taken and the predictions checked against reality. The audit findings should be reported to the person or people affected, and their participation sought in formulating changes in policy to remedy any unanticipated problems. The individual's sense of self-preservation and personal benefit, in such an ideal system, would give realistic feedback to governments on the acceptability of national policy. The combined experiences of governing and governed would forge a national consensus on future directions.

Glossary

1. **ABCC** Atomic Bomb Casualty Commission. Now called Radiation Effects Research Foundation (RERF)

2. **Alpha particle** an electrically charged (+) particle emitted from the nucleus of some radioactive chemicals, cf. plutonium. It contains 2 protons and 2 neutrons, and is the largest of the atomic particles emitted by radioactive chemicals. It can cause ionisation.

3. **Beta particle** an electrically charged (-) particle emitted from some radioactive chemicals. It has the mass of an electron. Krypton 85, emitted from nuclear power plants, is a strong beta emitter. Beta particles can cause ionisation.

4. **Curie** a measure of radioactivity. One curie equals 3.7×10^{10} nuclear transformations per second. Ci is the symbol used.
   - Microcurie: one-millionth of a curie.
     (3.7×10^{4} disintegrations per second) mCi is the symbol used.
   - Picocurie: one-millionth of a microcurie.
     (3.7×10^{-2} disintegrations per second) pCi is the symbol used.

5. **Dose** energy imparted to matter by nuclear transformations (radioactivity).
   - **Rad** = 100 ergs per gram.
     1 GRAY = 100 rad = 10,000 ergs per gram.
   - **Rem** = rads x Q
     where Q is a quality factor which attempts to convert rads from different types of radioactivity into a common scale of biological damage.
     1 SIEVERT = 100 rad.

6. **Gamma ray** short wave-length electromagnetic radiation released by some nuclear transformations. It is similar to X-ray and will penetrate through the human body. Iodine 131 emits gamma rays. Both gamma and X-rays cause ionisation.

7. **Half-life, biological** time required for the body to eliminate one-half of an administered quantity of a radioactive chemical.

8. **Half-life, physical** time required for half of a quantity of radioactive material to undergo a nuclear transformation. The chemical resulting from the transformation may be either radioactive or non-radioactive.

9. **Ionisation** sufficient energy is deposited in a neutral molecule to displace an electron, thus replacing the neutral

molecule with positive and negative ions.

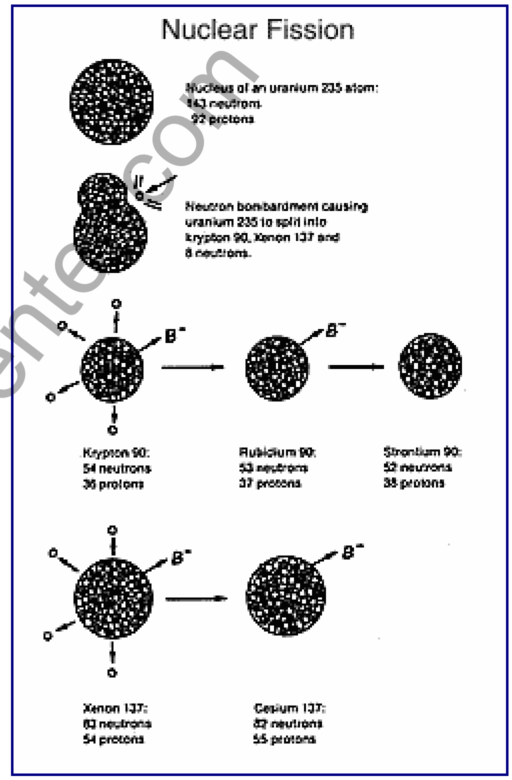
10. **Radiation** the emission and propagation of energy through space or tissue in the form of waves. It usually refers to electromagnetic radiation, classified by its frequency: radio, infrared, visible, ultraviolet, X-ray, gamma ray and cosmic rays.
    - **Natural background radiation** --
      emissions from radioactive chemicals which are not man-made. These chemicals include uranium, radon, potassium and other trace elements. They are made more hazardous through human activities such as mining and milling, since this makes them more available for uptake in food, air and water.
    - **Background radiation** --
      includes emissions from radioactive chemicals which occur naturally and those which result from the nuclear fission process. The meaning of this term is vague. In a licensing process it includes radiation from all sources other than the particular nuclear facility being licensed, even if the source includes a second nuclear facility located on the same site (US regulations). Radioactive chemicals released from a nuclear power plant are called `background' after one year.

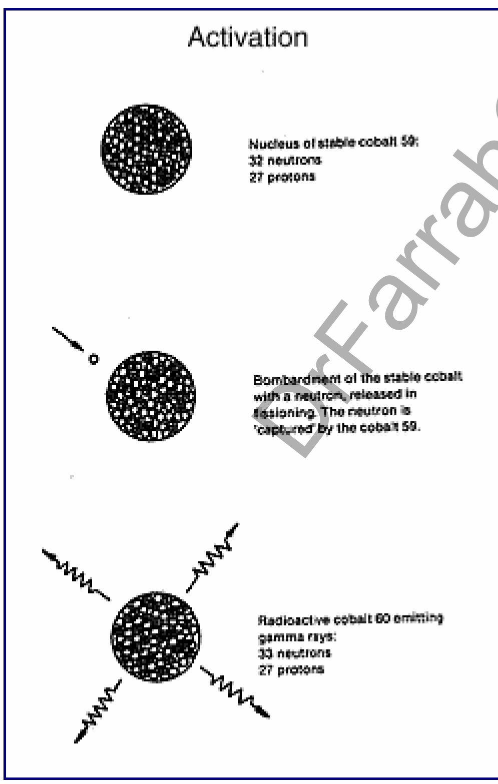
The Fissioning Process and its Consequences

In order to understand nuclear technology and its impact on human health, three atomic-level events must be understood: fissioning, activation and ionisation. Fissioning, i.e. the splitting of the uranium or plutonium atom, is responsible for producing radioactive fission fragments and activation products. These in turn cause the ionisation of normal atoms, leading to a chain of microscopic events we may eventually observe as a cancer death or a deformed child.

Radioactive fission products are produced in nuclear reactors. They are variant forms of the ordinary chemicals which are the building blocks of all material and living things. The radioactive forms of these chemicals were, prior to 1943, present in only trace quantities in isolated places in the environment as, for example, in South Africa where it appears that a small nuclear fission reaction occurred spontaneously about 1700 million years ago.

When a uranium atom is split or fissioned, it does not always split in the same place. The two pieces, called fragments, are chemicals of lower atomic weight than uranium. Each fragment receives part of the nucleus and part of the electrons of the original large uranium atom. The uranium atoms, of course, cease to exist after they are split. Instead, more than 80 different possible fission products are formed, each having the chemical properties usually associated with their structure, but having the added capability of releasing ionising radiation. X-rays, alpha particles, beta particles, gamma rays (like X-rays) or neutrons can be released by these `created' chemicals. All these can cause `ionisation', i.e. by knocking an electron out of its normal orbit around the nucleus of an atom they produce two `ions', the negatively charged electron and the rest of the atom which now has a net positive electrical charge.





The atomic structure of fission fragments is unstable. The atom will at some time release the destabilizing particle and return to a natural, low-energy, more stable form. Every such release of energy is an explosion on the microscopic level. With each fissioning, 2 or 3 neutrons are released which can strike a nearby U235 atom causing more fissioning in what is usually called a chain reaction.

The violence of the chain reaction is such that it can also yield what are called activation products, i.e. it can cause already existing chemicals in air, water or other nearby materials to absorb energy, change their structure slightly and become radioactive. As these high-energy forms of natural materials eventually return to their normal stable state, they can also release ionising radiation. About 300 different radioactive chemicals are created with each chain reaction.[1] It takes hundreds of thousands of years for all the newly formed radioactive chemicals to return to a stable state.

In a nuclear power plant the fissioning takes place inside the zirconium or magnesium alloy cladding which encloses the fuel rods. Most of the fission fragments are trapped within the rods. However, the activation products can be formed in the surrounding air, water, pipes and containment building. The nuclear plant itself becomes unusable with time and must eventually be dismantled and isolated as radioactive waste.

After fissioning, the fuel rods are said to be `spent'. They contain the greatest concentration of radioactivity of any material on the planet earth -- many hundreds of thousands of times the concentration in granite or even in uranium mill tailings (waste). The spent fuel rods contain gamma radiation emitters (which are similar to X-ray emitters) so they must not only be isolated from the biosphere, but they must also be shielded with water and thick lead walls. Direct human exposure to spent fuel rods means certain death.

In reprocessing, spent fuel rods are broken open and the outer cladding is dissolved in nitric acid. The plutonium is separated out for use in nuclear weapons or for fuel in a breeder or mixed oxide nuclear reactor. The remaining highly radioactive debris is stored as liquid in large carbon or stainless steel drums, awaiting some kind of solidification and burial in a permanent repository. Waste of lower radioactivity is buried in dirt trenches or -- as in Windscale (Sellafield) in England -- piped out to sea. The spent nuclear fuel rods and liquid reprocessing waste are called `high level radioactive waste'. It must be kept secure for hundreds of thousands of years -- essentially forever. Lower level waste may be equally long-lived, but it is less concentrated.

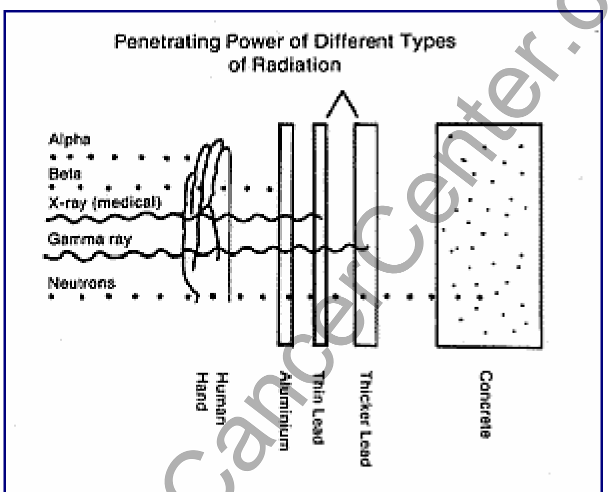
In above-ground nuclear weapon testing, there is no attempt to contain any of the fission or activation products. Everything is released into the air and on to the land. Some underground tests are also designed to release most of the radioactive particles; these are called crater shots or shots with unstemmed holes. Even when below-ground shots are designed to be contained, they normally lose the radioactive gases and some particulates. The radionuclides trapped in the ground can also migrate downwards in the earth to water reservoirs which provide irrigation and drinking water for human purposes, although this process is slow. Radioactive debris piped out to sea can be washed back on shore or can contaminate fish.

In all nuclear reactions, some radioactive material -- namely the chemically inert or so-called `noble' gases, other gases, radioactive carbon, water, iodine, and small particulates of plutonium and other transuranics (i.e. chemicals of higher atomic number than uranium) -- is immediately added to the air, water and land of the biosphere. In the far-distant future, all the long-lived radioactive material, even that now stored and trapped, will mix with the biosphere unless each generation repackages it. Our planet earth is designed to recycle everything.

The radioactive chemicals which escape to the biosphere can combine with one another or with stable chemicals to form molecules which may be soluble or insoluble in water; which may be solids, liquids or gases at ordinary temperature and pressure; which may be able to enter into biochemical reactions or be biologically inert. The radioactive materials may be external to the body and still give off destructive penetrating radiation. They may also be taken into the body with air, food and water or through an open wound, becoming even more dangerous as they release their energy in close proximity to living cells and delicate body organs. They may remain near the place of entry into the body or travel in the bloodstream or lymph fluid. They can be incorporated into the tissue or bone. They may remain in the body for minutes or hours or a lifetime. In nuclear medicine, for example, radioactive tracer chemicals are deliberately chosen among those quickly excreted by the body. Most of the radioactive particles decay into other radioactive `daughter' products which may have very different physical, chemical and radiological properties from the parent radioactive chemical. The average number of such radioactive daughters of fission products produced before a stable chemical form is reached, is four.

Besides their ability to give off ionising radiation, many of the radioactive particles are biologically toxic for other reasons. Radioactive lead, a daughter product of the radon gas released by uranium mining retains the ability to cause brain damage exercised by non-radioactive lead. Plutonium is biologically and chemically attracted to bone as is the naturally occurring radioactive chemical radium. However, plutonium clumps on the surface of bone, delivering a concentrated dose of alpha radiation to surrounding cells, whereas radium diffuses homogeneously in bone and thus has a lesser localized cell damage effect. This makes plutonium, because of its concentration, much more biologically toxic than a comparable amount of radium. Some allowance for this physiological difference has been made in setting plutonium standards, but there is evidence that there is more than twenty times more damage caused than was suspected at the time of standard setting.[2]

The cellular damage caused by internally deposited radioactive particles becomes manifest as a health effect related to the particular organ damaged. For example, radionuclides lodged in the bones can damage bone marrow and cause bone cancers or leukaemia, while radionuclides lodged in the lungs can cause respiratory diseases. Generalised whole body exposure to radiation can be expressed as a stress related to a person's hereditary medical weakness. Individual breakdown usually occurs at our weakest point. In this way, man-made radiation mimics natural radiation and causes the ageing or breakdown process to be accelerated.



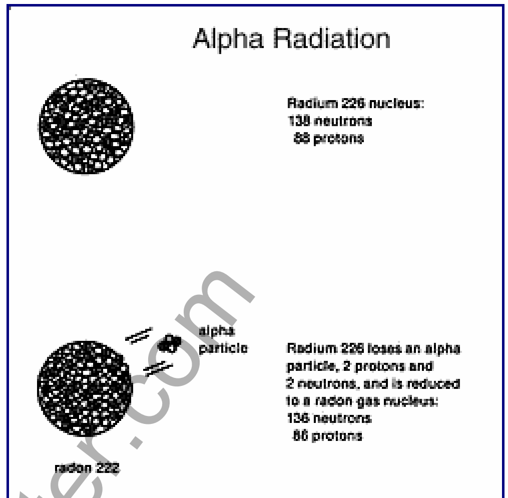
Radioactive Particles and Living Cells: Penetration Power

Radioactive fission products, whether they are biochemically inert or biochemically active, can do biological damage when either outside the body or within.

X-rays and gamma rays are photons, i.e. high-energy light-waves. When emitted by a source, for example, radium or cobalt, located outside the body, they easily pass through the body, hence they are usually called penetrating radiation. The familiar lead apron provided for patients in some medical procedures stops X-rays from reaching reproductive organs. A thick lead barrier or wall is used to protect the X-ray technician. Because X-rays are penetrating, they can be used in diagnostic medicine to image human bones or human organs made opaque by a dye. These internal body parts are differentially penetrable. Where bones absorb the energy, no X-rays hit the sensitive X-ray film, giving a contrast to form the picture of the bones on the radiation-sensitive X-ray plate. High-energy gamma rays, which easily penetrate bone, would be unsuitable for such medical usage because the film would be uniformly exposed. In photography jargon, the picture would be a `white out' with no contrasts. No radiation remains in the body after an X-ray picture is taken. It is like light passing through a window. The damage it may have caused on the way through, however, remains.

Some radioactive substances give off beta particles, or electrons, as they release energy and seek a stable atomic state. These are small negatively charged particles which can penetrate skin but cannot penetrate through the whole body as do X-rays and gamma rays.

Microscopic nuclear explosions of some radioactive chemicals release high-energy alpha particles. An alpha particle, the nucleus of a helium atom, is a positively charged particle. It is larger in size than a beta particle, like a cannon-ball relative to a bullet, having correspondingly less penetrating power but more impact. Alpha particles can be stopped by human skin, but they may damage the skin in the process. Both alpha and beta particles penetrate cell membranes more easily than they penetrate skin. Hence ingesting, inhaling or absorbing radioactive chemicals capable of emitting alpha or beta particles and thereby placing them inside delicate body parts such as the lungs, heart, brain or kidneys, always poses serious threats to human health.[3] Plutonium is an alpha emitter, and no quantity inhaled has been found to be too small to induce lung cancer in animals.



The skin, of course, can stop alpha or beta radiation inside the body tissue from escaping outwards and damaging, for example, a baby one is holding or another person sitting nearby. Also, it is impossible to detect these particles with most whole body `counters' such as are used in hospitals and nuclear installations. These counters can only detect X-rays and gamma rays emitted from within the body.

Splitting a uranium atom also releases neutrons, which act like microscopically small bullets. Neutrons are about one-fourth the size of alpha particles and have almost 2,000 times the mass of an electron. If there are other fissionable atoms nearby (uranium 235 or plutonium 239, for example) these neutron projectiles may strike them, causing them to split and to release more neutrons. This is the familiar chain reaction. It takes place spontaneously when fissionable material is sufficiently concentrated, i.e. forms a critical mass. In a typical atomic bomb the fissioning is very rapid. In a nuclear reactor, water, gas or the control rods function to slow down or to absorb neutrons and control the chain reaction.

Neutrons escaping from the fission reaction can penetrate the human body. They are among the most biologically destructive ot the fission products. They have a short range, however, and in the absence of fissionable material they will quickly be absorbed by non-radioactive materials. Some of these latter become radioactive in the process, as was noted earlier, and are called activation products.

Standard-setting Preliminaries

The complexity of setting health standards for exposure to the mixture of radioactive chemicals and ionising particles released in fissioning should be apparent. As a first move towards a reasonable subdivision of the hazard itself, separate standard setting was done for external radiation exposure, i.e. when the radioactive source was outside the body, and internal radiation exposure, i.e. when the radioactive source was inside the body.

Both these categories can then be subdivided into exposures to particular parts of the body or particular internal organs. The biological effect of an X-ray of the pelvic area differs from the biological effect of a dental X-ray, even if the radiation dose to the skin is the same. Plutonium lodged in the lungs has a different biological consequence from plutonium lodged in the reproductive organs. One can also consider exposures to X-rays, gamma rays, alpha or beta particles and neutrons separately, taking each as internal or external to the body.

There are further differences in health effects based on differences between people receiving the radiation. Special consideration needs to be given to those who, because of heredity or previous experience, are more susceptible to further damage than the norm or average. Special consideration should be given to an embryo or foetus, a young child, the elderly or those chronically ill.

The severity of health effects caused by internal exposures will depend on the biological characteristic of the radioactive chemical and the length of time it may be expected to reside in the body. Radioactive cesium, for example, lodges in muscles and is probably completely eliminated from the body in two years. Radioactive strontium lodges in bone and remains there for a lifetime, constantly irradiating the surrounding cells. The usual time required by the body to rid itself of half the radioactive chemical is called the `biological half-life' of that chemical.

Some radiation health effects are observable in the persons exposed; some effects are only seen in their children or grandchildren because the damage was to sperm or ovum.

X-rays, gamma rays and neutrons are able to inflict harm on humans even when the radioactive chemical emitting them is outside the body. Beta particles outside the body can cause serious burns and other skin anomalies, including skin cancer. Ionising radiations emitted from within the body by radioactive chemicals taken in by inhalation, ingestion or absorption are even more damaging because they are so close to delicate cell structures. The body is not able to distinguish between radioactive and nonradioactive chemicals and will as readily incorporate the one as the other into tissue, bone, muscle or organs, identifying them as ordinary nutrients. The radioactive chemicals remain in the body until biologically eliminated in urine or faeces, or until they decay into other chemical forms (which may or may not be radioactive). These daughter products and their chemical and radiological properties may be quite different from those of the parent radioactive chemical, for example, radioactive carbon decays into nitrogen. Radiochemical analysis of urine or faeces is the preferred test for most types of internal contamination with alpha or beta particles.

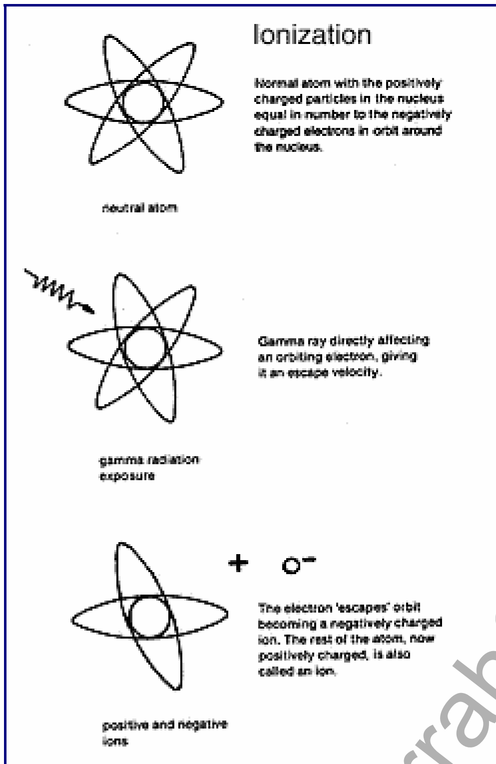
Within the Living Cell

The chaotic state induced within a living cell when it is exposed to ionising radiation has been graphically described by Dr Karl Z. Morgan as a `madman loose in a library'.[4] The result of cell exposure to these microscopic explosions with the resultant sudden influx of random energy and ionisation may be either cell death or cell alteration. The change or alteration can be temporary or permanent. It can leave the cell unable to reproduce (or replace) itself. Radiation damage can cause the cell to produce a slightly different hormone or enzyme than it was originally designed to produce, still leaving it able to reproduce other cells capable of generating this same altered hormone or enzyme. In time there may be millions of such altered cells. This latter mechanism, called biological magnification, can cause some of the chronic diseases and changes we usually associate with old age. One very specific mutation which can occur within the cell is the destruction of the cell's mechanism for resting which normally causes it to cease reproductive activities after cell division. This inability to rest results in a runaway proliferation of cells in one place, which, if not destroyed, will form a tumour, either benign or malignant. The abnormal proliferation of white blood cells is characteristic of leukaemia; red blood cell proliferation results in what is called polycythemia vera.

If the radiation damage occurs in germ cells, the sperm or ovum, it can cause defective offspring. The defective offspring will in turn produce defective sperm or ova, and the genetic `mistake' will be passed on to succeeding generations, reducing their quality of life until the family line terminates in sterilisation and/or death.[5] A blighted or abnormal embryonic growth can result in what is called a hydatidiform mole instead of a baby.

Exposure to radiation is also known to reduce fertility, i.e. women become unable to conceive or give birth.

Radiation can also damage an embryo or foetus while it is developing within the mother's womb. This is called teratogenic damage, or the child is said to have a congenital malformation rather than genetic damage. This means the damage is not automatically transmitted. For example, a deaf person, made so by a pre-birth injury, may have children with normal hearing.



The damage done within cells by random releases of the energy of photons, alpha, beta or neutron particles can occur indirectly through an effect called ionisation. As the energised photons or particles speed through the cells, they give energy to the electrons of chemicals already within the cells, enabling some electrons to break free from the rest of the atom or molecule to which they are attached. On the macro-level this would be comparable to an atomic explosion of a magnitude great enough to drive the earth or another planet out of its orbit around the sun. What was an electrically neutral atom or molecule is split into two particles -- a larger positively charged atom or molecule missing one of its electrons, and a small negatively charged electron expelled from its orbit around the nucleus of the atom. Both are called ions and the process is called ionisation.

The complex molecules making up living organisms are composed of long strands of atoms forming proteins, carbohydrates and fats. They are held together by chemical bonds involving shared electrons. If the ionising radiation displaces one of the electrons in a chemical bond, it can cause the chain of atoms to break apart, splitting the long molecule into fragments, or changing its shape by elongation. This is an `ungluing' of the complex chemical bonds so carefully structured to support and perpetuate life. The gradual breakdown of these molecular bonds destroys the templates used by the body to make DNA and RNA (the information-carrying molecules in the cell) or causes abnormal cell division. The gradual natural breakdown of DNA and RNA is probably the cellular phenomenon associated with what we know as `ageing'. It occurs gradually over the years with exposure to natural background radiation from the radioactive substances which have been a part of the earth for all known ages. There is evidence that exposure to medical X-rays accelerates this breakdown process.[6] There is ample reason to think that fission products lodged within the body will cause the same kind of acceleration of ageing. However, unlike medical X-rays, these radioactive chemicals damage cells by their chemical toxicity as well as their radiological properties.

The gradual breakdown of human bio-regulatory integrity through ionising and breakage of the DNA and RNA molecules gradually makes a person less able to tolerate environmental changes, less able to recover from diseases or illness, and generally less able to cope physically with habitat variations.

When the DNA of germ plasm is affected by radiation it can result in chromosomal diseases, such as trisomy 21, more commonly known as Down's Syndrome. Mentally retarded children, victims of Down's Syndrome, have been reported in Kerala, India, an area of high natural radioactivity.[7] Recently, cases of Down's Syndrome have been tentatively linked to women exposed to radioactive releases from the large plutonium fire at Sellafield (Windscale) in 1957.[8] While Down's Syndrome babies have long been associated with births to older women (those with higher accumulated exposure to natural background radiation),[9] the Sellafield-related cases involve women with an average age of 25 years.

So far we have considered the types of ionising radiation, the location of the source outside or within the body, and the difference between exposures to different parts of the body or to different people of various ages and states of health. These will all be important considerations underlying standard setting. Next, we need to be able to measure radiation, i.e. to quantify exposure.

Measuring Radiation

One way to approach the measurement of radiation is to count the number of nuclear transformations or explosions which occur in a given unit of radioactive substance per second. This measure is usually standardised to radium, the first radioactive substance to be discovered and widely used. One gram of radium undergoes 3.7 x 10^10 nuclear transformations or disintegrations per second. The activity of 1 gram of radium is called 1 curie (Ci), named for Madame Marie Curie, a Polish-born French chemist (1867-1934). Marie Curie discovered the radioactivity of thorium, polonium and radium by isolating radium from pitchblende. She and her daughter Irene were among the earliest known radiation victims, both dying of aplastic anaemia.

In recent radiation protection guides, the curie is being replaced by the becquerel, which indicates one atomic event per second. One gram of radium would equal 1 curie of radium or 3.7 x 10^10 becquerels of radium.

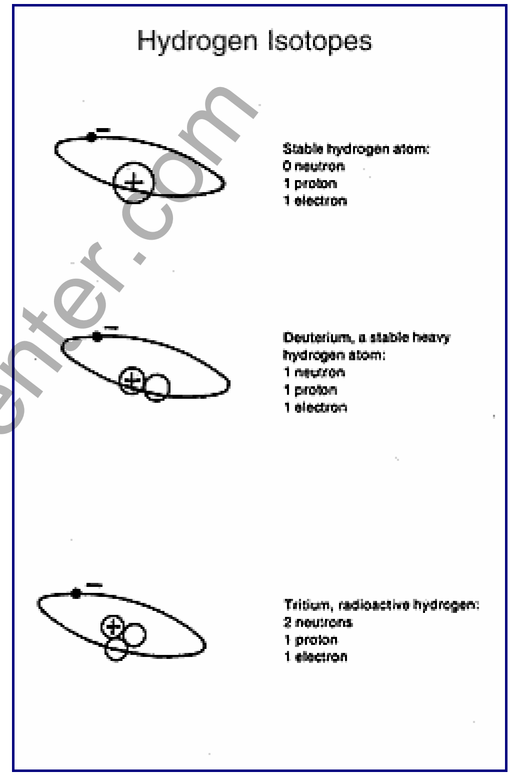
The energy released in nuclear disintegrations has the ability to do work, i.e. to move matter. In physics, the erg is a very small unit of work done. Lifting 1 gram of radium 1 centimetre requires 980 ergs of work. Any material exposed to the force from nuclear disintegrations at a rate of 100 ergs/gm is said to absorb one rad, i.e. *r*adiation *a*bsorbed *d*ose. There is no direct conversion from curies, which is related to the number of atomic events, to the rad dose, which is energy absorbed in tissue. The curie gives one an estimate of the number of microscopic transformations or explosions per second and the rad is an estimate of the energy release, absorbed by the surrounding tissue. On the macro-level, the word `explosion' tells us only of an event in time. A dynamite explosion or hydrogen bomb explosion adds information about the energy released.

Sometimes radioactivity is measured in counts per minute on a Geiger counter. A nuclear transformation within an energy range measured by the instrument and close enough to the instrument causes a noise or `count'. Most Geiger counters cannot detect alpha particle emitters like plutonium.

The radioactivity of elements which experience nuclear disintegrations is measured relative to radium. For example, it would take more than 1 million grams of uranium to be equivalent in radioactivity, i.e. to have the same number of nuclear events per second as 1 gram of radium has per second. Both 1 million grams of uranium and 1 gram of radium would be measured as 1 Ci. It has been the custom in the past to limit human exposure to uranium more for its toxic chemical properties (it is a heavy metal) than for its radioactivity. This practice may have underestimated damage caused by the biological storing of uranium in the liver.

When uranium decays, it passes through about 12 radioactive forms, called daughter products, before reaching a stable chemical form of lead. One of the radioactive daughter products of uranium is radium. Uranium released into drinking water or incorporated into food and human tissue today will eventually plague the world as radium and its other disintegration products: radon gas and the radioactive forms of polonium, lead and bismuth. The environmental and biochemical forces which may tend to reconcentrate these toxic materials in living cells are not well known. Although uranium occurs naturally, it has become much more available for entering into water, food, living cells and tissue since the mining boom which began shortly after the Second World War.

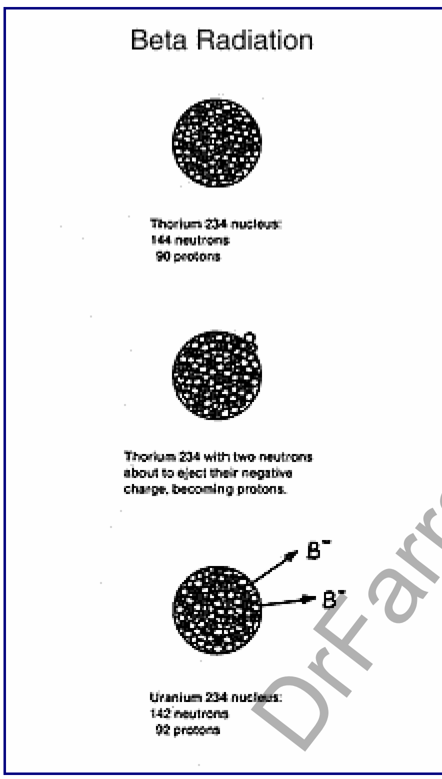
The activity which takes place in the nucleus of the uranium or radium atom is a `haphazard' event obeying the laws of random probabilities. An atom is characterised by its atomic number, that is, the positively charged particles in its nucleus, and by its atomic mass, expressed in atomic mass units (similar to the concept of weight), which includes both the number of protons (the atomic number) and the number of neutrons in the nucleus. Carbon, the most frequently occurring chemical in living material, is taken as having exactly 12 atomic mass units and other atoms are measured in relation to this. Carbon 14, which is radioactive, has two extra neutrons in its nucleus.



Hydrogen, another example, has an atomic number of 1 and an atomic mass of 1. Isotopes of hydrogen have the same atomic number (that is, the same number of positively charged particles in the nucleus and electrons in orbit around the nucleus) but a higher atomic mass. Deuterium or hydrogen 2, an isotope of hydrogen, has an atomic number of 1 and an atomic mass of 2. It is not radioactive. The increased atomic mass is due to an added neutron in the nucleus. Deuterium is in the `heavy water' used in the Canadian CANDU nuclear reactor. Hydrogen 3, called tritium, is radioactive, with two neutrons and a proton in the nucleus. It is produced in a nuclear reaction.

When radium 226 decays, it loses a positively charged alpha particle from its nucleus. An alpha particle has two protons (positive electrical charges) and a mass of 4 atomic units. This means a reduction in both radium's atomic number *and* atomic mass. Loss of the alpha particle changes radium 226 (transmutes it) into another element, radon 222. While radium 226 is a radioactive solid under normal conditions, radon 222 is a radioactive gas. Loss of one or more protons changes the chemical element into a different chemical. Absorption or loss of a neutron gives an isotope of the same chemical since chemical properties are determined by the number of protons and electrons in an atom.

The time required for half of any amount of radium 226 to transmute to radon 222 by these small explosions which emit alpha particles is 1,622 years. This is called the physical half-life of radium. Half of the radium literally disappears in that length of time, but radon gas is produced to replace it. Radon gas is radioactive and more mobile in air and water (it dissolves) than the solid radium. The half-life of radon is 3.82 days, after which half the gas will have disintegrated, again releasing alpha particles and transmuting into radioactive polonium 218, which is a solid. With a wind of 10 mph (or kph), the radon gas could travel 1,000 miles (or kilometres) from the point of origin before half of it would have decayed into its solid daughter products and been deposited on soil, leafy vegetables, tobacco, groundwater, human skin, lung tissue, etc. If the material receiving the radioactive daughter product is living, then it can carry the particles into its cells. Such contamination cannot be washed off.



When a negatively charged beta particle is released, there is a transmutation in which a neutron in the nucleus of the atom splits into a proton and an electron, the proton remaining in the nucleus and the electron given off as a fast-moving microscopic bullet. Beta particles are extremely small. The mass of an alpha particle is about 7,400 times that of a beta particle. Thorium 234 decays to uranium 234 (with a short-lived radioactive intermediary) by losing beta particles. Uranium and thorium are different elements, but have the same mass (atomic weight) since a neutron and proton have about the same mass. The thorium neutron becomes the uranium proton. The half-life of thorium 234 is 24.1 days, while the half-life of uranium 234 is 2.50 x 10^5, or 250,000 years. As was pointed out earlier, uranium nuclear events are not as frequent as those in radium, although they are destructive when they occur.

Given 12 grams of thorium 234, we would have 6 grams after 24.1 days, 3 grams after 48.2 days, 1.5 grams after 72.3 days, 0.75 grams after 96.4 days, etc. At the same time, the stock of uranium 234 would be increasing as the thorium decays into the new radioactive chemical.

There is no simple physical or chemical process such as temperature change or chemical bonding which can prevent these radioactive elements from decaying. Their nucleus is unstable and because all elements seek a stable low-energy state, they must at some time release particles in an effort to reach a resting state. The decay takes place in the nucleus of the atom regardless of whether the atom exists singly or is part of a molecule; is in the solid, liquid or gaseous state; is within the body or outside, and so on. The decay product after a radioactive disintegration may itself be radioactive, so disintegration does not put an end to the biological problems generated by these small explosions. This decay process must be taken into account when estimating the biological effects of internal exposure to radioactive material. Inhaled radon gas quickly becomes radioactive lead, bismuth or polonium in the bloodstream.

One should not confuse physical half-life with biological half-life, i.e. the time required to eliminate half of the material from the body through exhalation, urine or faeces. Cesium 137 and strontium 90 both have physical half-lives of almost thirty years, but cesium 137 is normally excreted from the body within two years while strontium 90 can be incorporated in bone for a lifetime.

One more measure needs to be introduced before radiation protection guides can be understood. Since the various kinds of radiation exposures need to be evaluated for biological impact and not just for the amount of energy absorbed by the tissue, the term rem, *r*oentgen *e*quivalent *m*an (or woman), was introduced. The rem dose is the rad dose times a quality factor Q. For external radiation Q is usually taken as 1, and rads and rems are used interchangeably. However, to reflect the greater biological damage done by alpha particles when inside the body, the rad dose may be multiplied by 20 to give the rem dose. This is another way of saying that the alpha particle does damage of an order of magnitude (20 times) greater when lodged within a tissue, bone or organ. For example, alpha particles giving a 2 rem (or rad) dose to skin would give a 40 rem dose to sensitive lung tissue when inhaled.

Theoretically, the rem dose measures equivalent biological effect, so that damage from X-rays, for example, would be the same as damage from alpha particles, when the dose in rem was the same. Unfortunately, living systems are too complex for such an approach to provide anything more than a good guess.

Sometimes references are made to a `fifty-year effective dose equivalent'. This is the full dose that would be received from an internal radionuclide if the dose were given at one time instead of being spread over two to fifty years.

Linear Energy Transfer (LET)

Measurement of the number of ionisations which radiation causes per unit distance as it traverses the living cell or tissue is called the linear energy transfer of the radiation. The concept involves lateral damage along the path, in contrast to path length or penetration capability. Medical X-rays and most natural background radiation are low LET radiation, while alpha particles have high LET. On the average, fission fragments have high LET.

The density of ionisation causes special problems in sperm and ova because the damage (protein breakage) is concentrated within a few cells. The two-year sterility of Japanese fishermen exposed to fallout from the 1954 hydrogen bomb test is probably an example of this effect. Sperm and the cells which produce sperm were damaged beyond their capability of prompt repair.

As a young girl in St George, Utah, USA, Elizabeth Catalan used to stand outdoors and watch the mushroom clouds raised by the Nevada nuclear tests float overhead. She has never been able to have children. She, like some other women in St George, is unable to carry a foetus to birth. Elizabeth's father, president of a local college, died prematurely of leukaemia. He used to go horse-riding with three friends and was frequently outside when the grey clouds laden with radioactive chemicals went over. Three of the four men are now dead from cancer.

Elizabeth's sister died in her late twenties of a thyroid disease which may have been caused by the radioactive iodine released in the atomic blasts. Elizabeth and her mother attribute many of their abnormal health problems, and those of family and friends, to the atomic fallout. No government studies have been undertaken to confirm or deny these claims. However, the situation was so widely recognised as abnormal by the local population that the Governor of Utah has filed a court claim against the US Federal Government for wrongful deaths of the people of Utah. About a thousand individual damage claims have entered the courts in the USA, and as part of the trial preparations Dr Carl Johnson undertook a detailed study of the Mormon population of Utah exposed to the fallout. It is reasonable to conclude that the health problems reported by the people of Utah are typical of what could be expected on the basis of theoretical radiobiology.[10]

On 10 May 1984, US District Court Judge Bruce S. Jenkins ruled on the first twenty-four claims of US government negligence in its conduct of nuclear testing. He has awarded $2.6 million in damages to ten claimants. This landmark, 489-page, carefully worded decision is expected to be appealed against by the US Federal Government.

In order to have a quantitative sense of the frequency of the different cell effects caused by radiation exposure, imagine a colony of 1,000 living cells exposed to a 1 rad X-ray (about the dose for one X-ray spinal examination). There would be two or three cell deaths, two or three mutations or irreparable changes in cell DNA and about 100,000 ionisations in the whole colony of cells -- ranging from 11 to 460 ionisations per cell.[11] While cells can repair some damage, no one claims that there is perfect repair even after only one such X-ray.

A comparable 1 rad exposure to neutrons which have higher linear energy transfer (LET) would be expected to cause more cell deaths and more mutations. The ionisations caused would range from 145 to 1,100 per cell.

Alpha particles which occur naturally would cause roughly 10 times as many cell deaths and mutations, and 3,700 to 4,500 ionisations per cell. Alpha particles have high linear energy transfer.

The average number of cell deaths and mutations caused by fresh fission particles (i.e. those present soon after detonation of a nuclear bomb) would be even greater, with the ionisations as frequent as 130,000 per cell.[12] In nuclear reactors, most of these extremely high-energy early fission fragments are enclosed within the fuel rod. In a nuclear bomb blast, they are all released but they decay very quickly and do not persist long in the environment.

If instead of thinking of a colony of living cells, we think of a person exposed to 1 rad (again about the skin dose from one spinal X-ray) of 1 MeV (million electron volts) energy, this corresponds to 2.2 billion (US) photons per cm^2 acting on the body. In the words of Karl Morgan, `It is inconceivable that all the billions of irradiated and damaged cells would be completely repaired.'[13] This unrepaired damage accumulates, eventually causing a reduction in the level of health that is normal for a particular age.

Stated very simply, ionising radiation seriously disrupts the chemistry of the cell. It can also kill or permanently change the cell. Every exposure to ionising radiation has this effect, and it is not possible for the body to perfectly repair all of the damage. Whether or not the residual unrepaired damage is of concern to the individual exposed is a personal value judgment. It is not at all clear that ordinary people find the damage `acceptable'' unless it initiates a fatal cancer, and yet this is the basis on which radiological safety standards are set in all nations of the world.

R. M. Sievert, the famous radiologist, who had supervised radiation therapy since 1926 at the Karolinska Institute in Stockholm, pointed out at an international meeting in 1950 that `there is no known tolerance level for radiation'.[14] A tolerance level is a level below which there is no damage (sometimes called a threshold). A safety level is ordinarily a fraction (one-tenth) of the tolerance level.[14]

Cell Damage Expressed as a Health Problem

An example to show the connection between cell damage and observable illness in the person exposed might help in understanding the problems posed by radionuclide (radioactive chemical) uptake, i.e. their ingestion, inhalation or absorption with food, air and water, into human bodies, with subsequent cell damage. The thyroid gland contains cells which produce thyroid hormone, which when released into the bloodstream causes the body functions such as breathing, digesting and reacting to stress to proceed at a certain rate. If the thyroid is `overactive', one might notice in the person increased pulse rate, nervousness, excitability, loss of body weight and, in females, more frequent menstruation. Such a person is often called `hyperactive' (hyper-thyroidism). A normal amount of thyroid hormone in the blood produces a normally active individual. An `underactive' or `hypoactive' thyroid can result in sluggishness, listlessness, weight gain and irregular and/or infrequent menstrual flow in women (hypothyroidism).

If radioactive iodine (I 131 or I 129) is ingested with food it will enter the blood and tend to accumulate in the thyroid. Radioactive iodine emits high-energy gamma radiation which can destroy thyroid cells, thus reducing total thyroid hormone production in the individual so affected.

A small amount of radioactive iodine would probably kill only a few cells and have little or no noticeable effect on health. However, if many cells are destroyed or altered, the hormone level would noticeably drop or the hormone itself would be slightly changed. The individual would become lethargic and gain weight. If properly diagnosed and severe enough to require medical intervention, this hypoactive thyroid condition can be controlled with artificially ingested thyroid hormone. A mild exposure experienced by a large population could cause a decrease in average thyroid hormone levels and an increase in average body weight, such as is occurring now in the North American population. The USA has been polluted with nuclear industries since 1943 and with radioactive iodine from weapon testing since 1951. Radioactive iodine is routinely released in small quantities by nuclear power plants and in large quantities by nuclear reprocessing plants. It is not part of the natural human environment. The connection between this pollution and the overweight problem has, unfortunately, never been seriously researched. There is no evidence to confirm or deny the hypothesis, but weight increase is a well-known biological response to radioactive iodine. The hypothesis is certainly plausible under the circumstances.

It is possible for thyroid cells to be altered but not killed by the radiation. The cellular growth mechanism may be damaged, allowing a runaway proliferation of cells. This results in a thyroid tumour, either cancerous (malignant), or non-cancerous (benign). Other possible radiation damage includes changes in the chemical composition of the individual's thyroid hormone, altering its action in the body and causing clinically observable symptoms not easily diagnosed or corrected.

There is an extremely remote possibility that these changes will be desirable, but the overall experience of randomly damaging a complex organism like the human body is that it is destructive of health.

An atomic veteran who participated in the nuclear tests which were conducted by the USA in the Bikini atoll in the late 1940s reported that he gained 75 lbs in the four years following his participation. The doctor diagnosed his problem as hypothyroidism. He also suffered from high blood pressure, chronic asthma and frequent bouts of bronchitis and pneumonia. He has had six tumours diagnosed since 1949, when he returned home from military service. Four have been surgically removed.

Damage to the thyroid of a developing foetus can cause mental retardation and other severe developmental anomalies.[15]

Other radionuclides will lodge in other parts of the body. If the trachea, bronchus or lung are exposed, the damage eventually causes speech or respiratory problems. If radioactive particles lodge in the stomach or digestive tract, the heart, liver, pancreas or other internal organs or tissues, the health problems will be correspondingly different and characteristic of the organ damaged. Radionuclides which lodge in the bone marrow can cause leukaemia, depression of the immune system (i.e. the body's ability to combat infectious diseases) or blood diseases of various kinds.

If the radiation dose is high, there is extensive cell damage and health effects are seen immediately. Penetrating radiation doses at 1,000 rad or more cause `frying of the brain' with immediate brain death and paralysis of the central nervous system. This is why no one dared to enter the crippled Three Mile Island nuclear reactor building during the 1979 accident. An average of 30,000 roentgens (or rads) per hour were being reported by instruments within the containment building. This would convert to a 1,000 rad exposure for two minutes spent inside the building. Such a dose to the whole body is invariably fatal.

The radiation dose at which half the exposed group of people would be expected to die, i.e. the 50 percent lethal dose, is 250 rad. The estimate is somewhat higher if only young men in excellent health (e.g. soldiers) are exposed. Between 250 and 1,000 rad, death is usually due to gross damage to the stomach and gut. Below 250 rad death is principally due to gross damage to the bone marrow and blood vessels. A dose of about 200 rad to a foetus in the womb is almost invariably fatal.

Penetrating radiation in doses above 100 rad inflicts severe skin burns. Lower doses produce burns in some people. Vomiting and diarrhoea are caused by doses above about 50 rad. There are some individuals who are more sensitive to radiation, however, showing typical vomiting and diarrhoea radiation sickness patterns with doses as low as 5 rad. An individual may react differently at different times of life or under different circumstances. Below 30 rad, for most individuals, the effects from external penetrating radiation are not immediately felt. The mechanism of cell damage is similar to that described for minute quantities of radioactive chemicals which lodge within the body itself, and our bodies are incapable of `feeling' damage to or death of cells. Only when enough cells are damaged to interfere with the function of an organ or a body system does the individual become conscious of the problem.

By sharpening our perceptions more subtle radiation effects can often become observable where once they went unnoticed. For example, a series of X-rays received by a young child may cause temporary depression of the white blood cells, and ten days to two weeks after the exposure the child will get influenza or some other infectious disease. Ordinarily the parent views the two events as unconnected.

Sometimes one can observe a mutation in a person who has experienced loss of hair after radiation therapy to kill tumour cells: hair that was formerly very straight can be curly when it grows again.

A plant whose flowers are normally white with red tips but which begins to form uniformly red flowers has mutated. Such an event has been observed by persons living in the vicinity of Sellafield in the United Kingdom.

The use of radiation therapy to destroy malignant cells also has observable results. It is rather like surgery in that it is deliberately used to kill the unwanted tumour cells.

Probable Health Effects resulting from Exposure to Ionising Radiation

Dose in rems (whole body)	Health effects Immediate	Delayed
1,000 or more	Immediate death. `Frying of the brain'.	None
600-1,000	Weakness, nausea, vomiting and diarrhoea followed by apparent improvement. After several days: fever, diarrhoea, blood discharge from the bowels, haemorrhage of the larynx, trachea, bronchi or lungs, vomiting of blood and blood in the urine.	Death in about 10 days. Autopsy shows destruction of hematopoietic tissues, including bone marrow, lymph nodes and spleen; swelling and degeneration of epithelial cells of the intestines, genital organs and endocrine glands.
250-600	Nausea, vomiting, diarrhoea, epilation (loss of hair), weakness, malaise, vomiting of blood, bloody discharge from the bowels or	Radiation-induced atrophy of the endocrine glands including the pituitary, thyroid and adrenal glands.

	kidneys, nose bleeding, bleeding from gums and genitals, subcutaneous bleeding, fever, inflammation of the pharynx and stomach, and menstrual abnormalities. Marked destruction of bone marrow, lymph nodes and spleen causes decrease in blood cells especially granulocytes and thrombocytes.	From the third to fifth week after exposure, death is closely correlated with degree of leukocytopenia. More than 50% die in this time period. Survivors experience keloids, ophthalmological disorders, blood dyscrasis, malignant tumours, and psychoneurological disturbances.
150-250	Nausea and vomiting on the first day. Diarrhoea and probable skin burns. Apparent improvement for about two weeks thereafter. Foetal or embryonic death if pregnant.	Symptoms of malaise as indicated above. Persons in poor health prior to exposure, or those who develop a serious infection, may not survive. The healthy adult recovers to somewhat normal health in about three months. He or she may have permanent health damage, may develop cancer or benign tumours, and will probably have a shortened lifespan. Genetic and teratogenic effects.
50-150	Acute radiation sickness and burns are less severe than at the higher exposure dose. Spontaneous abortion or stillbirth.	Tissue damage effects are less severe. Reduction in lymphocytes and neutrophils leaves the individual temporarily very vulnerable to infection. There may be genetic damage to offspring, benign or malignant tumours, premature ageing and shortened lifespan. Genetic and teratogenic effects.
10-50	Most persons experience little or no immediate reaction. Sensitive individuals may experience radiation sickness.	Transient effects in lymphocytes and neutrophils. Premature ageing, genetic effects and some risk of tumours.
0-10	None	Premature ageing, mild mutations in offspring, some risk of excess tumours. Genetic and teratogenic effects.

Radiation and Heredity

In 1943, Hermann Müller received a Nobel Prize for his work on the genetic effects of radiation and was a dominant figure in developing early radiation exposure recommendations made by the International Commission on Radiological Protection (ICRP).[16] He showed through his work with Drosophila, a fruit fly, that ionising radiation affects not only the biological organism which is exposed but also the seed within the body from which the future generations are formed.

In 1964 Hermann Müller published a paper, `Radiation and Heredity', spelling out clearly the implications of his research for genetic effects (damage to offspring) of ionising radiation on the human species.[17] The paper, though accepted in medical/biological circles, appears not to have affected policy makers in the political or military circles who normally undertake their own critiques of published research. Müller predicted the gradual reduction of the survival ability of the human species as several generations were damaged through exposure to ionising radiation. This problem of genetic damage continues to be mentioned in official radiation-health documents under the heading `mild mutations'[18] but these mutations are not `counted' as health effects when standards are set or predictions of health effects of exposure to radiation are made. There is a difficulty in distinguishing mutations caused artificially by radiation from nuclear activities from those which occur naturally from earth or cosmic radiation. A mild mutation may express itself in humans as an allergy, asthma, juvenile diabetes, hypertension, arthritis, high blood cholesterol level, slight muscular or bone defects, or other genetic `mistakes'. These defects in genetic make-up leave the individual slightly less able to cope with ordinary stresses and hazards in the environment. Increasing the number of such genetic `mistakes' in a family line, each passed on to the next generation, while at the same time increasing the stresses and hazards in the environment, leads to termination of the family line through eventual infertility and/or death prior to reproductive age. On a large scale, such a process leads to selective genocide of families or species suicide.[19]

It soon became obvious that the usual method determining a tolerance level for human exposure to toxic substances was inappropriate for ionising radiation. The health effects were similar to normally occurring health problems and were quite varied, ranging from mild to severe in a number of different human organ systems, and their appearance could be delayed for years or even generations.

Permissible Levels of Exposure

The US National Council on Radiation Protection and Measurement gave expression to the theoretical resolution of this human dilemma by articulating the implicit reasoning behind subsequent radiation protection standards development:[20]

1. A value judgment which reflects, as it were, a measure of psychological acceptability to an individual of bearing slightly more than a normal share of radiation-induced defective genes.
2. A value judgment representing society's acceptance of incremental damage to the population gene pool, when weighted by the total of occupationally exposed persons, or rather those of reproductive capacity as involved in Genetically Significant Dose calculation.
3. A value judgment derived from past experience of the somatic effects of occupational exposure, supplemented by such biomedical and biological experimentation and theory as has relevance.

This is now an internationally accepted approach to setting standards for toxic substances when no safe level of the substance exists.

In short, this elaborate philosophy recognises the fact that *there is no safe level of exposure to ionising radiation*, and the search for quantifying such a safe level is in vain. A *permissible* level, based on a series of value judgments, must then be set. This is essentially a trade-off of health for some `benefit' -- the worker receives a livelihood, society receives the military `protection' and electrical power is generated. Efforts to implement these permissible standards would then logically include convincing the individual and society that the `permissible' health effects are acceptable. This has come to mean that the most undesirable health effects will be infrequent and in line with health effects caused by other socially acceptable industries. Frequently, however, the worker and/or public is given the impression that these `worst' health effects are the only individual health effects. A second implication of the standards-based-on-value-judgments approach is that unwanted scientific research resulting in public scrutiny of these value judgments must be avoided.

The genetic effect considered by standard setters as most unacceptable is serious transmittable genetic disease in live-born offspring. These severely damaged children are usually a source of suffering for the family and an expense for society which must provide special institutions for the mentally and physically disabled. Severely handicapped people rarely have offspring; many die, are sterile or are institutionalised before they are able to bear children. Workers and the public are told that the probability of having such severely damaged offspring after radiation exposure within permissible levels is slight. By omission, a mildly damaged child or a miscarriage is implied to be `acceptable'.

From a column in the *Yomiuri Shinbun* (19 January 1965; evening edition)

A nineteen-year-old girl in Hiroshima committed suicide after leaving a note: `I caused you too much trouble, so I will die as I planned before.' She had been exposed to the atomic bomb while yet in her mother's womb nineteen years ago. Her mother died three years after the bombing. The daughter suffered from radiation illness; her liver and eyes were affected from infancy. Moreover, her father left home after the mother died. At present there remain a grandmother, age seventy-five; an elder sister, age twenty-two; and a younger sister, age sixteen. The four women had eked out a living with their own hands. The three sisters were all forced to go to work when they completed junior high school. This girl had no time to get adequate treatment, although she had an A-bomb victim's health book.

As a certified A-bomb victim, she was eligible for certain medical allowances; but the [A-bomb victims' medical care] system provided no assistance with living expenses so that she could seek adequate care without excessive worry about making ends meet. This is a blind spot in present policies for aiding A-bomb victims. Burdened with pain and poverty, her young life had become too exhausted for her to go on . . . .

There is something beyond human expression in her words `I will die as I planned before.'

Quoted in Kenzaburo Oe, *Hiroshima Notes*, YMCA Press Tokyo (English translator Toshi Yonezawa; English editor David L. Swain).

Standard setters judge that the most severe damage done directly to the person exposed is a fatal radiation-induced cancer, and again, this is a rare occurrence when exposure is within permissible levels. All other direct damage is by omission considered `acceptable'.

In its 1959 report recommending occupational standards for internal radiation doses (i.e. radioactive chemicals which are permitted to enter the body through air, water, food or an open wound), the International Commission on Radiological Protection (ICRP) formed the following definition:

> A *permissible genetic dose* [to sperm and ovum], is that dose [of ionising radiation], which if it were received yearly by each person from conception to the average age of childbearing [taken as 30 years], would result in an *acceptable* burden *to the whole population.*[16] [Emphasis added.]

This might be paraphrased to say that the general public (governments) may be willing to accept the number of blind, deaf, congenitally deformed, mentally retarded and severely diseased children resulting from the permissible exposure level. Defined this way, the problem becomes primarily an economic one, since society needs to estimate the cost of providing services for the severely disabled. Once reduced to an economic problem, some nations may choose to promote early detection of foetal damage during pregnancy and induced abortion when serious handicap is suspected. When a foetus is aborted prior to sixteen weeks' gestation the event may not need to be reported and included in vital statistics. It becomes a non-happening, and the nation appears to be in `good health', having reduced the number of defective births.

Mild mutations, such as asthma and allergies, are ordinarily not even counted as a `cost' of pollution. The economic burdens, `health costs', fall more on the individual and family than on the government. Their pain and grief do not appear in the risk/benefit equation. Parents and children are unaware of the `acceptable burden' philosophy.

The prediction of the magnitude of the burden of severe genetic ills on an exposed population is essential to this philosophy. However, the data accumulated at Hiroshima and Nagasaki did not give clear answers. Either through ineptitude or loss of survivors of the bombing, who died before their story was told, the researchers failed to find any severe genetic ills clearly attributable to the parental exposure to radiation at low doses.[21] Probably the more fragile individuals in the population died from the blast, fire and trauma of the bombs, the women not surviving long enough to become pregnant.[22]

Governments could not use the research on genetic damage in children of medical radiologists,[23] although this damage was measurable, because, in the early days, radiation exposure to physicians was not measured. No quantitative dose/response estimates could be derived.

Animal studies of radiation-related genetic damage abounded, and the recommending body, ICRP, used (and still uses) mouse studies as a basis of its official predictions of the severe genetic effects of ionising radiation in humans.

As late as 1980, a US National Academy of Science publication from its committee on the Biological Effects of Ionising Radiation[24] stated:

> New data on induced, transmissible genetic damage expressed in first generation progeny of irradiated male mice now allow direct estimation of first generation consequences of gene mutations on humans . . . As with BEIR I, a major obstacle continues to be the almost complete absence of information on radiation-induced genetic effects in humans. Hence, we still rely almost exclusively on experimental data, to the extent possible from studies involving mammalian species [i.e. mice].

These mouse studies are used as the basis of prediction, and permissible doses are set so that the expected number of severe transmittable genetic effects in children of those exposed could be presumed to be an *acceptable* burden for governments choosing a nuclear strategy.

The introductory section of ICRP Publication 2, 1959, states:

> The permissible dose for an individual is that dose, accumulated over a long period of time or resulting from a single exposure, which, in the light of present knowledge carries a negligible probability of *severe* somatic [damage to the individual] or genetic [damage to the offspring] injuries, furthermore, it is such a dose that any effects that *ensue more frequently* are limited to those of a minor nature that would not be considered *unacceptable* by the exposed individual and by competent medical authorities. Section 30.[16] [Emphasis added.]

Mild mutations are notably happenings of a minor nature, normally neither reported nor monitored in the population. They are likely to be statistically hidden by normal biological variations and unconnected in the mind of the individual or his/her physician with the exposure. The publication continues:

> The permissible doses *can therefore be expected to produce effects* [illnesses] that could be detectable only by statistical methods applied to large groups. Section 31.[16] [Emphasis added.]

In spite of this clarity, no such statistical audit of all health effects including chronic diseases in exposed people and mild mutations in their offspring has ever been done. More than 25 years have expired since this document was published and the world is more than 35 years into the nuclear age.

As late as 1965, ICRP Publication 9[25] stated:

> The commission believes that this level [5 rems radiation exposure per 30 years for the general public] provides *reasonable latitude* for the expansion of atomic energy programs in the foreseeable future. It should be emphasised that the limit may not in fact represent a proper balance between possible harm and probable benefit because of the uncertainty in assessing the risks and benefits that would justify the exposure. [Emphasis added.]

The committee protected itself against accusations of wrongdoing but failed to protect the public from its possible error. It defines its role as recommending, with the responsibility of action to protect worker and public health resting with individual national governments. Governments in turn tend to rely on ICRP recommendations as the best thought of internationally respected experts.

In spite of this uncertainty about responsibility and safety levels for exposure of the public, 5 rem per *year*, rather than per 30 years, was permitted for workers in the nuclear industry. The 5 rem per 30 years was set as the *average* dose to a population, with a maximum of 0.5 rem per year (15 rem per 30 years) for any individual member of the public.

For twenty years, between 1945 and 1965, health research on the effects of ionising radiation exposure has focused on *estimating* (not measuring) the number of *excess* radiation-induced fatal cancers and *excess severe* genetic diseases to be expected in a population (i.e. a whole country) given the *average estimated* exposure to radiation for the country. Disputes among scientists usually have to do with the magnitude of these numbers. Omitted from this research are other radiation-related human tragedies such as earlier occurrence of cancers which should have been deferred to old age or even might not have occurred at all because the individual would have died naturally before the tumour became life-threatening. These are not *excess* cancers, they are accelerated cancers. This approach also omits other physiological disorders such as malfunctioning thyroid glands, cardio-vascular diseases, rashes and allergies, inability to fight off contagious diseases, chronic respiratory diseases and mildly damaged or diseased offspring. The implications of such `mild' health effects on species survival seem to have either escaped the planners of military and energy technology, or to have been deliberately not articulated. Other obvious limitations of this national averaging approach include the failure to deal with global distribution of air and water with the result that deaths and the cumulative damage to future generations are not limited to one country.

The usual procedure for setting the standard for a toxic substance or environmental hazard is to decide the relevant medical symptoms of toxicity and determine a dose level below which these symptoms do not occur in a normal healthy adult. This cut-off point is sometimes called the tolerance level and it represents a sort of guide to the human ability to compensate for the presence of the toxic substance and maintain normal health. The tolerance level for a substance, if one can be determined, is then divided by a factor (usually 10) to give a safe level. This allows for human variability with respect to the tolerance level and also for biological damage which may occur below the level at which there are visible signs of toxicity, i.e. sub-clinical toxicity.

Human experience with ionising radiation had been recorded for more than fifty years prior to the nuclear age, the early history of handling radioactive material having been fraught with tragedy. The discoverer of the X-ray, W. K. Roentgen, died of bone cancer in 1923, and the two pioneers in its medical use, Madame Marie Curie and her daughter, Irene, both died of aplastic anaemia at ages 67 and 59 respectively. At that time, bone marrow studies were rarely done, and it was difficult, using blood alone, to distinguish aplastic anaemia from leukaemia. Both diseases are known to be radiation-related. Stories of early radiologists who had to have fingers or arms amputated abound. There were major epidemics among radiation workers, such as that among the women who painted the radium dials of watches to make them glow in the dark. Finally, there were the horrifying nuclear blasts in Hiroshima and Nagasaki.

The painful period of growth in understanding the harmful effects of ionising radiation on the human body was marked by periodic lowering of the level of radiation exposures permitted to workers in radiation-related occupations. For example, permissible occupational exposure to ionising radiation in the United States was set at 52 roentgen (X-ray) per year in 1925,[26] 36 roentgen per year in 1934,[27] 15 rem per year in 1949[28] and 5 to 12 rem per year from 1959 (depending on average per year over age 18) to the present.[29] Recently there has been an effort to increase permissible doses of ionising radiation to certain organs such as thyroid and bone marrow[30] in spite of research showing the radiosensitivity of these tissues. This newer trend probably reflects economic rather than physiological pressures, especially given the lack of an acceptable audit of physiological cost.

Radiation Protection Standards

In 1952 the International Commission on Radiological Protection (ICRP) issued its recommendations for limiting human exposure to external sources of radiation. The newly formed organisation accepted the standard agreed upon by nuclear physicists from the USA, Canada and the UK after the Second World War.[31] In 1959 it issued its recommendations for limiting human exposure to internal sources of radiation. The early ICRP dose limits per year were: 5 rem to the whole body, gonads or active bone marrow; 30 rem to bone, skin or thyroid; 75 rem to hands, arms, feet or legs; and 15 rem to all other body parts. These standards applied only to `man-made' sources, other than medical exposures for diagnostic or therapeutic purposes of benefit to the patient exposed.

ICRP Publication 2, in 1959, recommended no more than 5 rem per year external or internal exposure to the whole body due to inhalation, ingestion or absorption of radioactive chemicals into the body. Sometimes this was misinterpreted and workers were permitted to receive up to 5 rem internal and 5 rem external radiation exposure during one year. Another clause allowing averaging doses over years beyond age 18, gave excuse for still higher doses.

In terms of the amount of whole body dose received in a chest X-ray (about 0.03 rem at the present time), this recommendation for workers allowed the equivalent of 400 chest X-rays in some years with a 170 (present-day) chest X-ray average (external and internal) dose a year. Prior to 1970 some X-ray machines used in mass chest X-ray programmes gave as high as 3 rem per chest X-ray.

When one looks at dose to bone marrow, the permissible levels are even more troubling. By 1970 the average bone marrow dose for a chest X-ray was 0.001 to 0.006 rem averaging about 0.005 rem. In terms of dose to bone marrow, the ICRP radiation recommendation for workers permits up to the equivalent bone marrow dose of 1,000 chest X-rays per year.

ICRP recommended that members of the general public should receive no more than one-tenth of the occupational exposure or 0.5 rem per year, the equivalent bone marrow dose of about 100 present-day chest X-rays per year. The bone marrow dose is important for estimating the likelihood of causing bone cancer, leukaemia, aplastic anaemia or other blood disorders. Medical X-rays are less penetrating of bone than of soft tissue, making them valuable for `picturing' the bones. For this reason comparisons between radiation exposures of nuclear workers and medical X-ray exposures are more appropriately based on the bone marrow dose of each than on dose to soft tissue.

These radiation exposure recommendations stayed essentially the same until 1978, when in ICRP Publication 26 a recommendation was made to *raise* the levels of radiation permitted to humans from man-made sources of radiation (excluding that for medical purposes). For `internal consistency' of the recommendations there was some valid argument for scaling the standards for particular organ exposure in proportion to whole body exposure recommendations -- but scaling down as well as up would have accomplished this. For example, the ICRP reasoned that if the whole body could receive 5 rem per year, the active bone marrow should not be limited to 5 rem per year. This was used as a reason for increasing the permitted bone marrow dose from 5 rem to 42 rem with apparently little regard for the increased damage to bones and blood-producing organs.

ICRP Publication 26 also reiterates the need to allow human exposure in order to enjoy the `economic and social benefits' of the nuclear industries. It is difficult to understand how this conclusion was reached when so much new research is available documenting human illness associated with the present permissible exposure levels.[32] Perhaps, in view of contemporary scientific concern for *lowering* radiation exposures, ICRP Publication 26 recommendations are a political move to hold the line at present regulatory levels. At any rate, it appears to be a document with a political rather than a scientific purpose.

Some national regulatory agencies, such as the Atomic Energy Control Board in Canada, promptly implemented ICRP Publication 26 by increasing allowable radium levels in drinking water, thus reducing the clean-up cost for the uranium mining companies. Since some members of the national radiation protection community in Canada and elsewhere hold seats on ICRP, responsibility for what they recommend nationally cannot credibly be attributed to an international recommending body.

Failure to Audit Health

ICRP Publication 2 (1959) is one of special interest since it clearly states that radiation-induced severe genetic defects and cancer deaths resulting from the recommended standards would be expected to be rare and hardly distinguishable from `natural' variations due to non-radiation causes. The document goes on to point out that mild mutations in offspring and general ill health in those exposed would be the most frequent health effects of exposure, but these could not be `detected' except by epidemiological surveys. ICRP Publication 2 made no recommendation that this more subtle widespread degradation of public health *be* measured, although they mentioned that it *could* be measured.[33] At no time has there been an effort on the part of governments to document fully the more subtle health effects.

Workers, military service personnel and the general public have been given the impression that exposure to radiation involves a slight risk of dying of cancer and that one's chances of escaping this are better than the chances of escaping an automobile accident. The probabilities of early occurrence of heart disease, diabetes mellitus, arthritis, asthma or severe allergies -- all resulting in a prolonged state of ill health -- are never mentioned. Most people are unaware of the fact that ionising radiation can cause spontaneous abortions, stillbirths, infant deaths, asthmas, severe allergies, depressed immune systems (with greater risk of bacterial and viral infections), leukaemia, solid tumours, birth defects, or mental and physical retardation in children. Most of the above-mentioned tragedies affect the individual or family unit directly and society only indirectly. Dr R. Mole, a member of ICRP and the British NRPB, stated: `The most important consideration is the generally accepted value judgment that early embryonic losses are of little personal or social concern.'[34] There are similar value judgments made with respect to other health effects. The health problems are externalised, i.e. placed beyond the responsibility of government, and they are borne by individuals and their families.

The risk/benefit decision making which arose from balancing `health effects' against `economic and social benefit' is based on risk and benefit to *society*, i.e. governments, rather than cost to the individual or family unit. Value judgments have been made as to the level of health effects and deaths `acceptable' to the public. Because of military control of A-bomb studies and military need for personnel to handle radioactive materials, many of these value judgments were cloaked in secrecy for the sake of `national security'. The subject was made to seem complicated to outsiders; the decisions were reserved for the experts. The now famous words of President Dwight D. Eisenhower, `Keep the public confused'[35] about nuclear fission so that the government could gain public acceptance of above-ground weapon testing in Nevada, have certainly been accomplished. A growing number of people in the USA and elsewhere have lost all faith in statements made by government officials, because of the scientific jargon used to mask the truth.

In the USA, external radiation exposure records (film badge and TLD[a] readings) are carefully kept for workers, but corresponding health records for workers are not kept and analysed nationally. In other countries, especially those with socialised medicine, excellent health records are kept but accurate radiation exposure records are neglected. Collection and analysis of radiation exposure records together with experience of ill health, including chronic long-term (non-fatal) problems, are required in order accurately to assess radiation-related health problems. Merely recording the first cause of death for workers is not sufficient.

a. TLD -- thermoluminescent dosimeter, used to measure individual radiation doses of workers. It contains radiosensitive chips and must be carefully screened for the kind of radiation it is meant to detect. In a pilot study done in the US some processors of TLDs discovered that some of their chips were completely insensitive to the type of radiation for which they were purchased. See P. Plato and G. Hudson, `Performance Testing of Personnel Dosimetry Services: Alternatives and Recommendations for a Personnel Dosimetry Testing Program', US Nuclear Regulatory Commission (NUREG/CR-1593), 1980, p. 9.

The public is at an even greater disadvantage than the worker. There are no cumulative records of radiation exposures for individual members of the public from nuclear testing, military or commercial nuclear industries anywhere in the world. Because of this record-keeping vacuum, it is difficult, if not impossible, to challenge ICRP predictions.

Inadequate collection of information on public health by governments makes it difficult for scientists concerned about rising radiation exposure levels to document changes in public health. The problem is not that they are poor scientists, but that they do not have access to detailed information, since governments have failed to collect it. The health changes which can be detected, in spite of poor records, represent only a minute proportion of the undocumented whole.

One key to understanding what priority a country places on the health consequences of national defence and energy choices is the precision of its measurements of resultant health effects. Measurements of health effects can be made through controlled animal experiments or observation of the effects of unplanned human exposures. These measurements serve as an audit of human health effects or as an after-the-fact check on the accuracy of predictions. This technique of controlled observation is normally applied when a new drug or new medical procedure is introduced into general use. A prediction must prove its worth in real life.

As one would expect, predictive dose/response estimates for radiation exposure and specifically chosen severe health effects have been prolific in the USA. Not only has the USA maintained a tight control over and interest in research on the Japanese survivors of radiation exposure from the nuclear bombing of Hiroshima and Nagasaki, it also has a system of government-sponsored research laboratories controlled successively by the Atomic Energy Commission, the Energy Research and Development Administration and the Department of Energy. These bodies have been the source of almost all the original research papers published between 1945 and 1977 on the health effects of ionising radiation. Because radiation-related health effects are the result of the production, testing and use of atomic weapons, military goals and military secrecy have influenced both the selection of research questions and release of findings in the USA. The nuclear age is predicated on public acceptance of its consequences, hence `proving' that public acceptance is `rational' has a very high priority for government and industry-employed scientists. They have a vested interest in verifying the status quo.

Prior to the above-ground nuclear weapon test ban in 1963, the USA set off at least 183 atmospheric nuclear tests, more than all the other nations of the world combined. About half these tests were set off near the Pacific Trust Territory of Micronesia, given into US protection by the United Nations after the Second World War, and the other half were set off on the 1,350 square miles at the

Nevada Test Site north of Las Vegas. By 1978 the USA had set off an additional 400 nuclear bombs below ground in Nevada, some of which were officially admitted to have `leaked' large amounts of radioactive chemicals. Some of the tests were of UK weapons since it also uses the Nevada test site. Underground tests are still taking place in the USA,[36] the USSR and French Polynesia. In the Northern Hemisphere, above-ground tests have also been detonated by the USSR, China and India and in the Southern Hemisphere by France and South Africa.

The Nevada nuclear tests have spread radiation poisons throughout central and eastern United States and Canada, and produced in the stratosphere a layer of radioactive material which encircles the globe. They also cause nitric oxides to form in the atmosphere which then descend on earth as acid rain. Radioactive chemicals can now be found in the organs, tissues and bones of every individual in the Northern Hemisphere, and the contamination from past nuclear explosions will continue to cause environmental and health problems for hundreds of thousands of years, even if all nuclear activities are stopped today. Siberian tests affect the north polar region.

Pollution of the Southern Hemisphere, though less than in the North, is progressing along the same path. Although the United States and Great Britain have ceased nuclear tests in the Pacific Ocean, France has not ceased them, and it appears that South Africa has begun to test. Brazil, Argentina and other nations are thought to be developing a nuclear weapon capability.

A 1977 report of the United Nations Scientific Committee on the Effects of Atomic Radiation stated that twenty atmospheric nuclear tests -- six in the Northern Hemisphere and fourteen in the Southern Hemisphere -- plus unnumbered underground tests, took place between 1972 and 1977. As a result of this nuclear testing radiation doses to the population increased by about 2 percent in the Northern Hemisphere, and 6 percent in the Southern Hemisphere over the dose estimated in 1970. The nuclear weapon testing carried out between 1972 and 1977 was insignificant when compared to that between 1945 and 1963.

> The total global dose commitment for each individual from all nuclear explosions carried out before 1976 ranges from about 100 mrad (in the gonads) to about 200 mrad (in the bone-lining cells). In the northern temperate zone the values are about 50 percent higher, and in the southern temperate zone about 50 percent lower than these estimates.[37]

This estimate does not include the dose from radioactive carbon (carbon 14) which, because of its 5730-year half-life, persists in the human food chain and has not yet taken its total human toll. For comparison purposes, 100 mrad is about equal to the amount of radiation a person receives from naturally occurring radiation in one year of chronological ageing. The dose commitment from nuclear weapon testing is spread over a fifty-year period, with most of the dose being delivered in the first year.

There has been no lack of victims of radiation pollution in the West to study both for refinement of predictions of biological harm and checks of adequacy of predictions relative to the real-life situation. Checking *adequacy* of predictions means including all hidden costs which must eventually be paid, including damage to agriculture and the biosphere. Government oversight should also include full disclosure of findings to the public as a test of the acceptability of such costs and as an evaluation of the judgments made for society by the nuclear experts.

Can Health be Measured?

The obvious answer is that we can, of course, find a way to measure gains and losses in health; only the will to do so is lacking. In order to measure subtle changes in health a good reporting and recording system is needed, together with protection of privacy for the individual and ongoing biostatistical analysis of the accumulated data. Whole bodies of statistical theory, such as sequential analysis, used for product quality control, and system analysis, used to predict the outcome of a complicated interaction between interdependent variables, need to be used in the public health sector. This could provide a public health technology capable of managing military and industrial technology, able to act as a reality check on predictions and to give an early warning of dangers arising from within the big-system and threatening survival of the nation or, indeed, the human race. Biostatistical detection of problems needs to be followed by pathological, cytological and other confirmatory studies. No such serious systematic commitment to public health is evident relative to this nuclear issue anywhere in the world. Governments seem unaware that economic and military policies can be destructive of human health within the nation.

The radiation issue is further confused by statisticians and public health specialists who claim that there are some inherent and insurmountable problems which make it impossible to monitor the public health effects of pollution.[38] These professionals seem to limit themselves, consciously or unconsciously, to current inadequate data collection systems and mathematical tools. This is like deciding that it is impossible to travel to the moon on the basis that the only transportation possible is a commercial airliner. It will very probably require grass-roots scientific initiatives to cause governments to begin to act as strongly in protection of public health as they act to promote their own economic and military strategies.

Many people have become aware that national security strategies, especially nuclear weapon stockpiling, are increasing individual insecurity. Capital-intensive national economic strategies, designed to balance import/export dollar flow, can cause havoc with the individual citizen who is having to cope with the side effects of inflation and unemployment. Government neglect of health monitoring relative to economic and military strategies is, however, not yet perceived by the public as a serious problem.

It should be obvious that pollution of the environment with fission products will cause a wide variety of physiological changes in people exposed to them. There is little disagreement among scientists with regard to this conclusion.

There is also little controversy about the tragedy caused by uncontrolled fission -- whether deliberately or accidentally unleashed, whether from a nuclear reactor accident or an exploding warhead.

The question which causes controversy is: which health effects should be recognised as important for fiscal planning? `Important' may relate to public acceptance of the problem, or to the money which must be paid out for damage compensation, or the productive years lost through premature disability or death of workers. Once the significant health effects are identified, then quantification of these effects becomes the primary societal goal. This gives rise to scientific controversies. Present scientific controversy on low level radiation has to do with estimating the number of radiation-induced `excess cancer deaths' that are related to a given dose of ionising radiation. Fiscal concern has centered on radiation-induced excess cancers, and scientific concern on predicting this outcome.

These excess cancer numbers are important to planners who wish to show that their development schemes are less harmful than an alternative scheme. They are important to government officials who have to decide whether or not to assume the financial burden of ordering evacuation of a danger zone in a reactor accident like that at Three Mile Island. They are important to insurance companies, since they allow calculation of theoretical liability due to an accident. They are important to legislators who need to balance risks (deaths) against some military or economic benefit. They are important to strategic planners who calculate `collateral damage', i.e. the number of human deaths, after an atomic attack.

These numbers of specifically selected health effects, `radiation-induced excess cancer fatalities', predicted on the basis of the `average man's' reaction to a given average dose of ionising radiation, are of little meaningful use to individuals. Firstly, no one is really an `average man'. Also, populations may vary in the proportion of people with above-average susceptibility to radiation damage. Secondly, a `radiation-induced excess cancer fatality' is one of the least likely of the health problems to occur with exposure to low level radiation. More likely scenarios are radiation acceleration of a cancer caused by some other factor, such as cigarette smoking[b], earlier clinical expression of cancer, benign tumours, or related non-malignant health problems. Thirdly, even if the individual has a cancer it is almost impossible to present evidence to prove that his or her cancer is the *excess* one which would not have occurred without the radiation exposure. Therefore compensation for damage is almost impossible to obtain. Only one veteran from the USA exposed to radiation in its nuclear bomb programme has ever received compensation: Orvile Kelly. About six months before he died the Veterans Administration admitted that his illness could be attributed to radiation exposure. About 1,000 veteran claims have been refused.[39]

b. Many researchers believe that the primary carcinogen in cigarettes is polonium 210, a radioactive daughter product of radon gas which is released from uranium mining and i mill tailings.

The usual `rational' approach to risk versus benefit planning by governments is irrational from the point of view of the individual. It undermines the individual's ability to control and understand his or her environment and to hold government accountable to its electorate.

The human body is delicately fashioned and the unique gifts of each person are meant to enrich the human family. Crude quantification of random damage to people which is used to justify political or military gains of the nation may be labelled sophisticated barbarianism. It is the decadent thinking of those who have accepted the rule of force and who envision a future earth ruled by a powerful country (the USA or the USSR) with a monopoly of weapons of mass destruction, able to terrorise all other nations into co-operating with some form of global economy and resource-sharing of their choosing.

The Health Physicist

A word needs to be said about health physics, a relatively new academic specialty which has emerged since the dropping of the atomic bomb. Systematic study of radiation health questions began at the University of Chicago when the first nuclear reactor began operating on 2 December 1942. Primarily under the leadership of physicists E. O. Wollan, H. M. Parker, C. C. Gamertsfelder, K. Z. Morgan, J. C. Hart, R. R. Coveyou, O. G. Landsverk and L. A. Pardue, it grew to become a recognised graduate-level discipline.[40]

While this was a much-needed specialty, its bias toward the so-called `hard sciences' -- physics, chemistry and engineering -- and neglect of the `soft sciences' -- biology, physiology and psychology -- has tended to create radiation safety officers rather than health professionals.

In a message from the President of the Health Physics Society published in the July 1971 issue of the *Health Physics Journal*,[41] Dade W. Moeller stated:

> I think it is interesting to note the results of a tabulation of the records of the 2,862 health physicists who joined the Society from 1960 through 1969. The data showed that although half of the new members *with college degrees* had attended graduate school for a year or

> more, 21.6 per cent of the new members *did not have a college degree*. [Emphasis added.]

Membership of the Health Physics Society is broader than, but includes, licensed health physicists who have passed qualifying examinations. These latter are generally required to have a college degree with a major in physics, chemistry or engineering, and one year of graduate training in radiation measurement and safety practices.

Dade W. Moeller goes on to describe the members who had a college degree:

> by far the greatest percentage (24.0 per cent) received their bachelor's degrees in physics and/or mathematics. Next was chemistry (15.8 per cent) and then engineering (13.6 per cent).

Even members of the Health Physics Society have complained about the pro-nuclear bias of its publication[42] but seldom has this been expressed as clearly as in this address by Dade Moeller. After reporting a need for 2,000 to 3,000 more health physicists by the year 2000 just to support the operation of nuclear power stations, he urged members to be active: `To paraphrase an old adage, "let's all put our mouth where our money is".'

Unfortunately, the Health Physics Society probably will not be in the vanguard speaking on behalf of workers and members of the public whose health is at risk from nuclear industries. The obvious and outstanding exception to this statement is Dr Karl Z. Morgan who has remained an open, honest and independent student of life. Dr Morgan has spoken out courageously on behalf of lowering worker and public exposures to radiation and avoiding all unnecessary exposures. In so doing he has alienated many of his peers and jeopardised his own research and teaching position. Karl Morgan was a friend of Hermann Müller and he remembers the geneticist's warning about undermining the health of a nation and its children.[43]

The United States, a leading nuclear nation, has failed to provide any reliable human health study either to confirm or to deny its prediction of the human health effects of exposure to chronic low level radiation, or even to provide a systematic health follow-up of the significant groups exposed to radiation so that there will in time be such a reliable study. The predictions of health effects are based primarily on the effects reported at Hiroshima and Nagasaki and the applicability of these estimates to chronic low dose exposure of a normal population has always been doubtful.[21]

The US government has also failed to supply the worker or the public with trained health professionals whose jobs are independent of the nuclear industry and whose training and background would enable them to alert people to a slowly deteriorating health situation. Adequate record-keeping and reporting would force public awareness of the problems, and probably the facing of ultimate questions such as: for what perceived benefit can society sacrifice the health of future generations?

The health physicist, while serving a necessary safety function within nuclear installations, does not fulfil the role of a health advocate in this situation. His or her job is to enforce regulations, not to question them and to support the nuclear plant management even if it is clear that the management is wrong.[44] This is not so much the result of malice as a normal outcome of believing `permissible' is the same as `safe', and trust that present regulations are `very safe'. It thus becomes acceptable to handle radioactive material and to cheat a little on over-exposures.

The first key to understanding governments' commitment to ensuring the survival of individual citizens is its adoption of a verification process for testing its prediction of severe health effects resulting from its economic and military strategies. In the United States, this leads to a preliminary judgment that individuals have been considered expendable. Health damage from radiation associated with military or economic ventures has not been easily traceable to the cause or immediately apparent to the public. No efforts deliberately to trace and make public all the health effects have been made. In fact, when any research has begun to show such effects, the researcher has been `discredited' and his or her funding discontinued.

On the basis of the US government's neglect of follow-up and record keeping on radiation-exposed people, and its lack of concern for mild genetic effects, the unrest of the US public with respect to further development of nuclear technology is highly rational. Continuance of present government neglect and unconcern is at best irrational and at worst genocidal. We may observe the same syndrome of irrational behaviour in other nuclear nations which are experiencing public unrest.

Although the problems inherent in the production of nuclear weapons and nuclear power reach a climax of scale in the United States, they are experienced in all countries with nuclear technology. Where one country may keep excellent public health records, it has poor records of individual radiation exposures. Where another keeps detailed radiation exposure histories, it has no detailed medical history. As long as part of the information is missing, the worker and general public are forced to rely on predictions made by `recognised experts' which are not verified by factual studies. This is really a forecast with no audit allowed. The promotion of nuclear technology in developing nations as the industry loses support in the developed world is even more disturbing.

Before moving on, some of the concepts of radiation protection important for nuclear workers, the general public and medical personnel need to be emphasised. First, an assurance of `no immediate danger' with respect to exposure to ionising radiation is empty when it masks long-term effects resulting from incorporation of radiochemicals in sensitive tissues and/or the results of biological magnification of cell damage or radiation-induced genetic mistakes. Secondly, independent testing of urine, faeces, exhalation, tissues removed in surgery, baby teeth and hair for radioactivity, must become routine laboratory tests for medical diagnostic purposes as we try to cope with the fission product pollution already in the biosphere. Thirdly, when assessing the impact of any leak, abnormal release, normal effluence or waste which is radioactive, it is essential to know the radiochemicals involved: their physical and biological properties, the potential pathways to human beings and the length of time they remain toxic. Fourthly, the health effects of radiation differ with the age of the person exposed, his or her physical status and prior experience.

The second key to governmental priorities in decision-making is found in the historical context of the nuclear development. This is examined later. First we must try to understand the practices of nuclear technology in the military and civil sectors.

References:

§

1. `Fission Products' in *The Effects of Nuclear Weapons* (3rd edn), US Department of Defence and US Department of Energy, 1977, Section 1.60 to 1.66.

§

2. Karl Z. Morgan, `Suggested Reduction of Permissible Exposure to Plutonium and Other Transuranium Elements', *American Industrial Hygiene Association Journal*, August 1975, pp. 567-75.

§

3. Karl Z. Morgan, `Hazards of Low-Level Radiation', *Yearbook of Science and the Future*, Supplement of the *Encyclopedia Britannica*, 1980.

§

4. Karl Z. Morgan, `Reducing Medical Exposure to Ionizing Radiation', *American Industrial Hygiene Association Journal*, May 1975, pp. 361-2.

§

5. H. Müller, `Radiation and Heredity', *American Journal of Public Health*, vol 54, no. 1, 1964, pp. 42-50.

§

6. R. Bertell, `X-ray Exposure and Premature Aging', *Journal of Surgical Oncology*, 9, 1977, pp. 379-91.

§

7. N. Kochupillai, I. C. Verma, et al., 'Down's Syndrome and Related Abnormalities in the Area of High Background Radiation in Coastal Kerala', *Nature*, 262: 60, 1976.

§

8. P. M. E. Sheehan and I. B. Hillary, `An Unusual Cluster of Down's Syndrome, Born to Past Students of an Irish Boarding School', *British Medical Journal*, vol 287, 12 November 1983. Also Letters and Author's reply, *British Medical Journal*, vol 288, 14 January 1984.

§

9. L. S. Penrose and G. F. Smith, *Down's Anomaly*, Churchill, London, 1966.

§

10. Carl J. Johnson, `Cancer Incidence in an Area of Radioactive Fallout Downwind from the Nevada Test Site', *Journal of the American Medical Association*, vol 251, no. 2, 13 January 1984.

§

11. H. B. Jones, `Estimation of Effect of Radiation Upon Human Health and Life Span', Proceedings of the Health Physics Society, June 1956.

§

12. L. H. Gray, `Biological Damage by Different Types of Ionizing Radiation' in *Biological Hazards of Atomic Energy*, Clarendon Press, Oxford, 1950.

§

13. Karl Z. Morgan, `Risk of Cancer from Low Level Exposure to Ionizing Radiation', American Association for the Advancement of Science, Washington, DC, 17 February 1978.

§, §

14. R. M. Sievert, `Tolerance Levels and Swedish Radiation-protection Work', Proceedings of the Health Physics Society, June 1956, p. 181.

§

15. M. Eisenbud, `Radioactivity in the Environment -- Radioactive Concentration in the Fetal Thyroid', *Pediatrics* (Supplement), 41, Part II, 1968, p. 174.

§, §, §, §

16. ICRP Publication 2, Pergamon Press, Oxford 1959.

§

17. H. Muller, `Radiation and Heredity', *American Journal of Public Health*, vol 54, no. 1, 1964, pp. 42-50.

§

18. `Biological Effects of Ionizing Radiation', BEIR III, US National Academy of Science, National Academy Press, 1980, pp. 74-5.

§

19. R. Bertell, `Ionizing Radiation Exposure and Human Species Survival', *Canadian Environmental Health Review*, vol 25, no. 2. June 1981

§

20. `Basic Radiation Protection Criteria', US National Council on Radiation Protection Report no. 39, pp. 58-60.

§, §

21. A. M. Stewart, `Delayed Effects of A-Bomb Radiation: A Review of Recent Mortality Rates and Risk Estimates for Five-year Survivors', *Journal of Epidemiology and Community Health*, vol 36, no. 2, June 1982, pp. 80-6.

§

22. R. Bertell, Letter to the Interagency Task Force on Low-Level Ionizing Radiation (director F. Peter Libassi); published in *Public Comments on the Work Group Reports*, US Department of Health, Education and Welfare, June 1979.

§

23. S. Macht and P. Lawrence, `National Survey of Congenital Malformations Resulting from Exposure to Roentgen Radiation', *American Journal of Roentgenology*, 76, 1955, pp. 442-66.

§

24. `Biological Effects of Ionizing Radiation'. BEIR 111, US National Academy of Science, National Academy Press, 1980, pp. 74-5.

§

25. ICRP Publication 9, Pergamon Press, Oxford. 1965.

§

26. Recommended by pioneer researchers A. Mutscheller and R. M. Sievert in 1925. Recommended for international use by the forerunner of the International Commission on Radiological Protection (ICRP) in 1934. Used in most countries until 1950.

§

27. Recommended by the US National Commission on Radiological Protection (NCRP), 17 March 1934.

§

28. Recommended hy the US NCRP, 7 March 1949 and hy ICRP, July 1950, for total body exposure.

§

29. Recommended by ICRP, April 1956 and US NCRP, 8 January 1957, for total body exposure. This allows for 5 rem per year combined dose from sources external to the body, ingested or inhaled sources. This standard is used in most countries of the world today.

§

30. ICRP 26, Pergamon Press, Oxford. 1978.

§
31. See *op cit*., note 12, pp. 96 and 123. British, Canadian and American nuclear physicists met in Chalk River, Canada in September 1949 and at Buckland House, UK in August 1950 to agree on radiation-dose levels for workers. Their recommendations were accepted by ICRP.

§
32. Karl Z. Morgan, `Hazards of Low-Level Radiation'. *Yearbook of Science and the Future*, Supplement of the *Encyclopedia Britannica*. 1980.

§
33. ICRP Publication 2, Pergamon Press, Oxford, 1959. See also *Statistics Needed for Determining the Effects of Environment on Health*, US DHEW Publication no. (HRA) 77-1459 (1977).

§
34. R. Mole, `Radiation Effects on Pre-natal Development and their Radiological Significance', *British Journal of Radiology*, 52:614, 1979, pp. 89-101.

§
35. `Ike Sought Confusion Over Nuclear Testing', Associated Press Report, 20 April 1979.

§
36. For information on past and present nuclear tests in Nevada contact: Citizen's Call, 1321 East 400 South. Salt Lake City, Utah 84102, USA. Official reports on nuclear tests in Nevada are available from the US Department of Energy which operates the test site: *Announced United States Nuclear Tests*, July 1945 to December 1983. NVO-209 (REV.4), January 1984.

§
37. `Sources and Effects of Ionizing Radiation', UN Scientific Committee on the Effects of Atomic Radiation, Report to the General Assembly, nos. 90-91, 1977.

§
38. C. E. Land, `The Hazards of Fallout or of Epidemiologic Research', Editorial in *New England Journal of Medicine*, 300 (8): 431-2, 1979.

§
39. For ongoing information on atomic veterans contact: International Association of Atomic Veterans, 236 Massachusetts Avenue. N.E., Suite 306, Washington, DC 20002, USA (tel: 202-543-7711).

§
40. Karl Z. Morgan and J. E. Turner (eds). *Principles of Radiation Protection, A Textbook of Health Physics*, John Wiley, New York, 1967. See Preface.

§
41. Dade Moeller, `The President's Message', *Health Physics Journal*, vol 21, 1971, p. 1.

§
42. See dialogue in Letters, *The Health Physics Society Newsletter*, vol XII, May and August 1984.

§
43. Karl Z. Morgan, `Hazards of Low-Level Radiation'. *Yearbook of Science and the Future*, Supplement of the *Encyclopedia Britannica*, 1980.

§
44. Personal correspondence to the author from Karl Z. Morgan, first Chairperson of the Committee on Internal Exposures, ICRP and director of the health physics programme at Oak Ridge

National Laboratory and Neely Professor, School of Nuclear Engineering, Georgia Institute of Technology.