Section 1 Nature and Sources of Radiation

1.1 Radioactivity, radiation and X-rays

We need to understand that there is a difference between two very common terms, radioactivity and radiation. But before we look at this in detail, we need to picture an atom.

An atom is simply the smallest indivisible part of an element or matter. It comprises of a nucleus which contains 2 ‘sub-atomic’ particles which have certain electrical charges. These are Protons (positive) and Neutrons (neutral). Surrounding this nucleus is a third sub-atomic particle known as an electron and this particle has a negative charge.

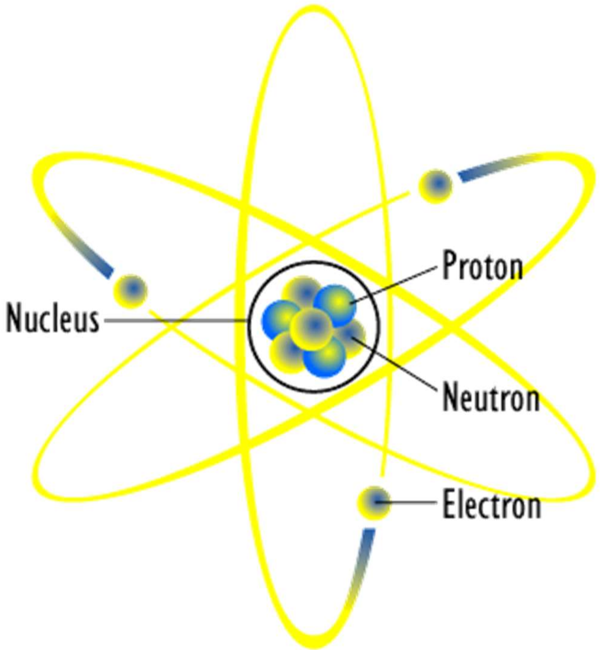


Fig 1 The basic atom showing the 3 major components, Proton, Neutron and Electron

All atoms have an equal balance of protons to electrons, so the charges are equal and opposite. However, some atoms can become unstable, and this results in an imbalance of electrical charges. The atom will attempt to neutralise this by way of emitting radiation.

Radioactivity comes about because some atomic nuclei have an excess of protons and neutrons. Radioactivity is the emission of particulate radiation and/or electromagnetic radiation (in the form of waves) from unstable atomic nuclei. The stability of the nucleus is dependent on the number of protons and neutrons in the nucleus and if there are too many protons the nucleus loses energy through the emission of an alpha particle. If there are too many neutrons the nucleus loses energy through the emission of a beta particle. If the nucleus is still unstable it will lose its excess energy through the emission of electromagnetic radiation.

Radiation on the other hand is simply the transmission of energy through space, from very long radio waves to short, high-energy x-rays. Radiation is represented by the electromagnetic spectrum. Note this includes particulate radiation and acoustic radiation not just electromagnetic radiation

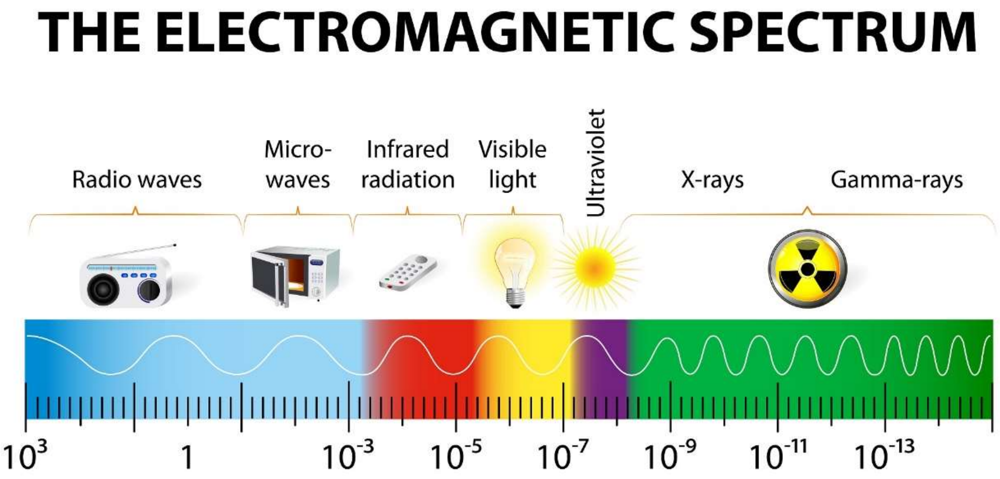


Fig 2 Radiation is represented by the electromagnetic spectrum which also includes visible light.

X-Rays are a type of radiation produced artificially, unlike radiation that comes from the decay of an unstable atom. They are therefore produced electronically via an X-ray generator, but it should be stated from the outset that X-rays can carry with them the same hazards as radiation from 'natural' sources. X-rays can be effectively turned up or down to increase or decrease its penetrating power into matter. So, from here we can split X-rays into two groups: 'soft' X-rays, and 'hard' X-rays. The only difference between these two types is the amount of power used to generate the X-ray for its application. Typically, 'soft' X-rays have a lower 'electronvolt' or eV rating. 'Hard' X-rays have much higher electronvolt ratings and are often expressed as keV, typically in the range of 5-10 keV. Soft X-rays are used in industry for the measurement of chemical composition of materials, such as those emitted from an XRF gun (X-ray fluorescence) and are considered to be of a low power as the X-ray only needs to penetrate the material a small distance. The resulting 'fluorescence' is an indication of the chemical composition of the material being tested.

Hard X-rays on the other hand, with its much higher penetration into matter, are typically used for medical imaging and security and screening systems. The reason for this is because the purpose of a hard X-ray is to penetrate the material being assessed and have enough power to go through the material to reach X-ray detectors. This is what forms the image on your typical medical X-ray. Depending on the density or thickness of the material being tested, the trained operator can simply adjust the keV to suit. Therefore, the keV required to perform an X-ray on the hand on a human will be much less than the keV required to penetrate the chest, or thicker parts of the body.

For applications such as airport security and screening, the adjustment of keV allows the trained operator to see varying levels of detail, which is of course very important from a security point of view.

Also of interest is the fact that a CT scan is effectively ‘slices’ of X-rays that are produced when a patient is slowly moved through a CT scanner. These images can be stitched together to provide an almost 3-dimensional view of the body part being examined. From a medical point of view, it is important to note that if you work with X-ray machines and/or radioactive material as part of your job, then this information should be passed on to your doctor when scripted an X-ray for medical purposes. The reason is simple; all exposures to either X-rays or radiation need to be justified. Most of the time the benefit of the medical image will outweigh the risk associated with exposure. However, exposure to ANY form of radiation (in particular ‘ionising radiation’) carries with it increased risk of cancers and radiation sickness. The last thing any individual wants to do is to be effectively ‘double-dosing’ by exposure in the work environment, and medical imaging. It all adds up at the end of the day, so ideally any exposure is justified and managed accordingly so that any individual doses are kept “As Low As Reasonably Achievable” (referred to later in this course as ALARA).

1.2 Types of radiation – natural sources (decaying unstable atoms)

There are four types of radiation that can be emitted from a decaying and unstable atom:

- ***Alpha (α)*** is a relatively safe form of radiation and consists of relatively heavy subatomic particles with a positive charge (protons). They react very strongly with matter which causes them to have a low penetration into matter. In air, alpha particles will only travel a few centimetres, and they do not penetrate the dead layer on the surface of the human skin.

- ***Beta (β)*** consists of much lighter subatomic particles which carry a negative charge (electrons). Beta radiation from different sources may have different penetrating power. Some beta will be able to penetrate through air a number of meters, while others are limited to a few centimetres.

- ***Gamma (γ)*** is similar to x-rays that are used for radiographic purposes (although gamma radiation is sometimes used for radiographic purposes for non-human applications). This type is to be treated with caution as gamma can penetrate the skin. A shield of lead or concrete (thickness dependant) will stop gamma penetration.

- ***Neutron*** is not always referred to but is a major part of industrial moisture measurements and detection of hydrogen (H+). Most of the time, Neutron radiation comes from the interaction of alpha material and low atomic number materials such as Beryllium and results in an uncharged subatomic particle. In most cases neutron radiation is present due to an alpha source (Americium 241) that is mixed with Beryllium. This interaction allows the 'knock-off' of neutrons.

1.3 Quantities and units

When we measure weight, we use the units of grams and when we measure distance we use the units of metres. For radioactivity we use the **Becquerel**, or **Bq.** The reason we do this is to honour the person who discovered radioactivity, Antoine Henri Becquerel. A Bq is a very small number and represents 'one atomic transformation per second'. This means that for a radionuclide with an activity of 1Bq, 1 atom decays per second. In all reality we are dealing with many more 'atoms per second' hence you will often see the prefix mega, giga and tera.

- 1 megabecquerel = 1 million Bq (10^6)
- 1 gigabecquerel = 1 thousand million Bq (10^9)
- 1 terabecquerel = 1 million million Bq (10^{12})

Still used in NZ is the unit of **curie (Ci)** or its subunits the **millicurie (mCi)** and **microcurie (µCi).** The table below shows some useful conversions.

- 1 Ci = 37 GBq
- 1 mCi = 37 MBq
- 1 µCi = 0.037 MBq
- 1 TBq = 27 Ci
- 1 GBq = 27 mCi
- 1 MBq = 27 µCi

Therefore 1 Ci is equal to 37 thousand million transformations per second, i.e. 37GBq.

The activity of the radioactive material will gradually decrease over time due to the decay of the radionuclide, according to its half-life. When using instruments that contain a radioactive source, the user will quite often have to account for the loss of activity due to the decay process. This is usually by way of a 'standard count' which essentially uses the onboard detectors to take measurements directly from the source.

1.3 Dose - Absorbed dose

Absorbed dose is the amount of energy deposited in any material by ionizing radiation. This relates to the biological effects of the radiation and is often referred to simply as the 'dose'.

The unit for this is the **'gray, (Gy)'** which is equal to one joule per kilogram (1 Gy = 1 J/Kg). Submultiples of the gray are often used usually in the form of a **microgray (µGy)**

1.4 Effective dose

This relates to the bodies susceptibility to absorbing radiation on a per organ basis. In the human body the effective dose is calculated by multiplying actual organ doses by 'risk weighting factors' (which indicate individual organs relative radio sensitivity to developing cancer). These numbers are totalled, and the result is termed the 'effective whole body dose' or simply 'effective dose'. The units for the effective dose are the **sievert (Sv),** and the submultiples **millisievert (mSv)**, and **microsieverts (µSv)**.

Organ or Tissue	**Weighting Factor**
Gonads	0.08
Red bone marrow	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Bladder	0.04
Breast	0.12
Liver	0.04
Oesophagus	0.04
Thyroid	0.04
Skin	0.01
Bone surfaces	0.01
Salivary glands	0.01
Brain	0.01
*Remainder	0.12

* Remainder includes adrenals, extrathoracic tissue, gall bladder, kidneys, lymph nodes, muscle, oral mucosa, pancreas, prostate, small intestine, spleen, uterus and cervix.

1.4.1 Whole body, eye and extremity exposures

The *whole body* literally means the whole body as this is the location of the blood-producing and vital organs. Since the whole body contains the most radiation-sensitive organs, it has the lowest limit. The guideline for this is less than 20mSv per year averaged over a defined period of 5 years. Therefore it is possible to receive an annual dose up to 50 mSv so long as the 5 year average does not exceed 20mSv.

There is considerable difference between a dose to the whole body (trunk) and a dose to the extremities (hands, feet etc). The reason for this is the lack of sensitive organs found in these places. Anyone servicing instruments may be exposed to

extremity doses and as a guideline this should not exceed 500mSv a year. This can be monitored by way of 'Ring Monitors' (a TL badge worn on the hands) which are available from providers in NZ. Eye exposure should not exceed 150 mSv per year.

1.5 Types of X-Ray equipment

1.5.1 X-Ray sources

As mentioned in section 1.1 of this course manual, X-rays come in many different forms depending on their respective penetrating power, which is known as the 'electronvolt' or eV. Soft X-rays, as used in XRF guns have a low eV, whereas hard X-rays used in medical imaging and security and screening systems have a much higher eV or keV value to penetrate the matter in its entirety. Soft X-rays simply need to hit the surface of the material being tested to make certain compounds 'fluoresce' and from there the device can determine, for example, the presence of heavy metals in contaminated soils. Hard X-rays only work effectively if they can pass through the material being tested, and reach an X-ray detector of some sort (in medical imaging of old, this was simply a piece of X-ray film, which is similar to photographic film. Nowadays 'digital' detectors are the norm, and this allows for both the radiographer and in some cases, the patient, to see the image almost instantly). Some examples of these devices can be found below:

- **XRF devices** (X-Ray Flourescene) – hand held 'guns' that are popular in environmental applications, especially for contaminated sites. They also have an application in Geology to determine the composition of rocks and soils. Interestingly, they are also used in precious metal recycling to determine the purity of the precious metal in question.

Fig 3 – An example of a XRF gun being used in the field.

- **Security and screening systems** – pretty much par for the course when entering and leaving airports, courtrooms and prisons. These devices use a range of hard X-rays to determine if anything undesirable is contained within and opaque container (e.g. suitcases, laptop bags, hand bags and carry-on luggage). They are also used heavily in the food and beverage industries to detect for any foreign objects or inconsistencies with the product being sold. As with any device that emits ionizing radiation, there are risks involved.

However, modern X-ray security and screening equipment is, by their nature, intrinsically safe due to its construction. But as always, it is best practice to be aware of the hazards, and make sure your devices are regularly serviced and calibrated.

Fig 4 – A typical X-ray security device used in airports, prisons and also food and beverage manufacturing facilities.

Section 2 Biological Effects of Ionising Radiation and Risks

2.1 A brief history…

First, let’s have a look at some history with regards to the interaction of man and radiation.

Within weeks after the first X-ray pictures were revealed to the world in January 1896, news on the discovery spread throughout the world. Soon afterward the penetrating properties of the rays began to be exploited for medical purposes, with no inkling that such radiation might have deleterious effects.

Fig 4 The first X-ray ever taken. This is Frau Röntgen’s left hand

The first reports of X-ray injury to human tissue came later in 1896. Elihu Thompson, an American electrical engineer, deliberately exposed one of his fingers to X-rays and provided accurate observations on the burns produced. That same year, Thomas Alva Edison was engaged in developing a fluorescent X-ray lamp when he noticed that his assistant, Clarence Dally, was so ‘”poisonously affected” by the new rays that his hair fell out and his scalp became inflamed and ulcerated. By 1904 Dally had developed severe ulcers on both hands and arms, which soon became cancerous and caused his early death.

During the next few decades, many investigators and physicians developed radiation burns and cancer, and more than 100 of them die as a result of their exposure to X-rays. These unfortunate early experiences eventually led to an awareness of radiation hazards for professional workers and stimulated the development of a new branch of science – namely, radiobiology.

Fig 5 An example of a burn from X-rays

Radiations from radioactive materials were not immediately recognised as being related to X-rays. In 1906 Henri Becquerel, the French physicist who discovered radioactivity, accidentally burned himself by carrying radioactive materials in his pocket. Noting that, Pierre Curie, the co-discoverer of radium, deliberately produced a similar burn on himself. Also around 1925, a number of women employed in applying luminescent paint that contained radium to clock and instrument dials became ill with anaemia and lesions of the jawbones and mouth; some of them subsequently developed bone cancer.

In 1933 Ernest O. Lawrence and his collaborators completed the first full scale cyclotron at the University of California at Berkeley. This type of particle accelerator was a copious source of neutrons, which had recently been discovered by Sir James Chadwick in England. Lawrence and his associates exposed laboratory rats to fast neutrons produced with the cyclotron and found that such radiation was about two and a half more effective in killing power for rats than were X-rays.

Considerably more knowledge about the biological effects of neutrons had been acquired by the time the first nuclear reactor was built in 1942 in Chicago. The nuclear reactor, which was to become a prime source of energy for the world, produces an enormous amount of neutrons as well as other forms of radiation. The widespread use of nuclear reactors and the development of high energy particle accelerators, another prolific source of ionising radiation, have given rise to ‘health physics’. This field of study deals with the hazards of radiation and protection against such hazards. Moreover, since the advent of space flight in the late 1950’s, certain kinds of radiation from space and their effects on human health have attracted much attention. The protons in the Van Allen radiation belts (two doughnut shaped zones of high energy particles trapped in the earth’s magnetic field), the protons and heavier ions ejected in solar flares, and similar particles near the top of the atmosphere are particularly important.

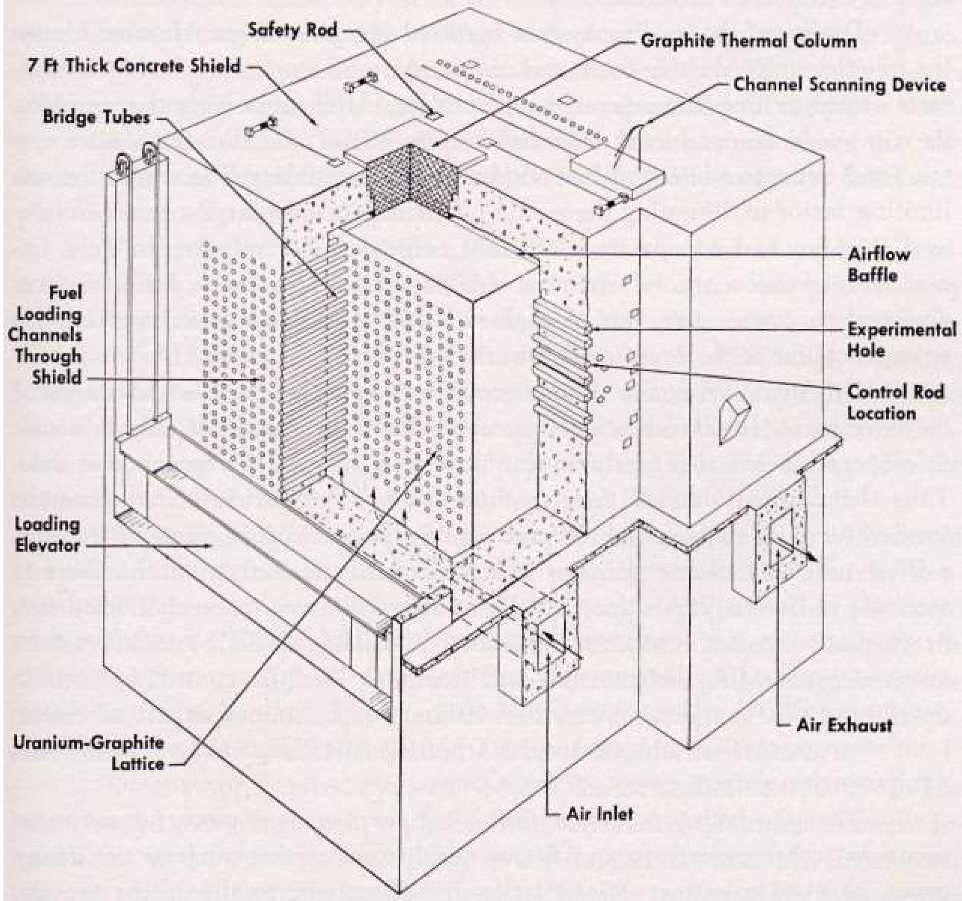


Fig 6 Schematic diagram of the world's first nuclear reactor, nicknamed CP-1

2.2 Deterministic and Stochastic effects

Ionizing radiation can cause deterministic (or non-stochastic) or stochastic (random) effects. *Deterministic effects* appear if a minimum radiation dose is exceeded. Above that threshold, the effects are readily observed in most or all exposed people and the severity increases with dose. The occurrence and severity of a deterministic effect in any one individual are reasonably predictable, for example a radiation burn. Examples of deterministic effects are *cataracts, skin damage (erythema), depression of red blood cell formation, and decreased fertility.*

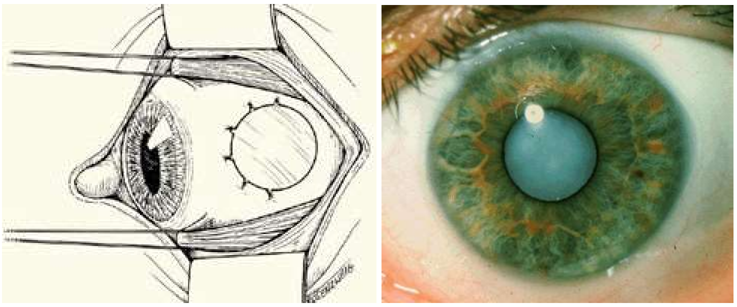


Fig 7 Cataracts is an example of a deterministic effect

Skin damage, similar to a burn, for example does not occur in any individuals as a consequence of radiation exposure except for rather large doses and the larger the dose above the threshold the greater the damage to the individual. If the whole body is exposed to very high doses of radiation greater than a 100 Gy, death will occur within hours due to damage to the central nervous system (CNS). Severe nausea and vomiting will occur within minutes followed by disorientation, loss of coordination, and difficulty with breathing, diarrhoea, convulsions, coma and finally death.

Stochastic effects can be taken as those that are usually delayed and do not appear for several years or decades after the original exposure. The most important stochastic effect is the induction of cancer, and then effects like inheritable genetic damage. It is thought that there is no minimum threshold for these effects; as dose decreases the effects are still expected to occur, but with lower frequency. However, the uncertainties at low doses (10 mSv or less) are very large

2.3 LD-50 and damage mechanisms

Single radiation doses over about 1 Gy cause radiation sickness; acute effects include nausea, vomiting, and diarrhoea, sometimes accompanied by fever and possible haemorrhage. The victims may die in a few hours, days, or weeks. Other acute effects can include sterility and radiation burns, depending on the absorbed dose and the rate of exposure.

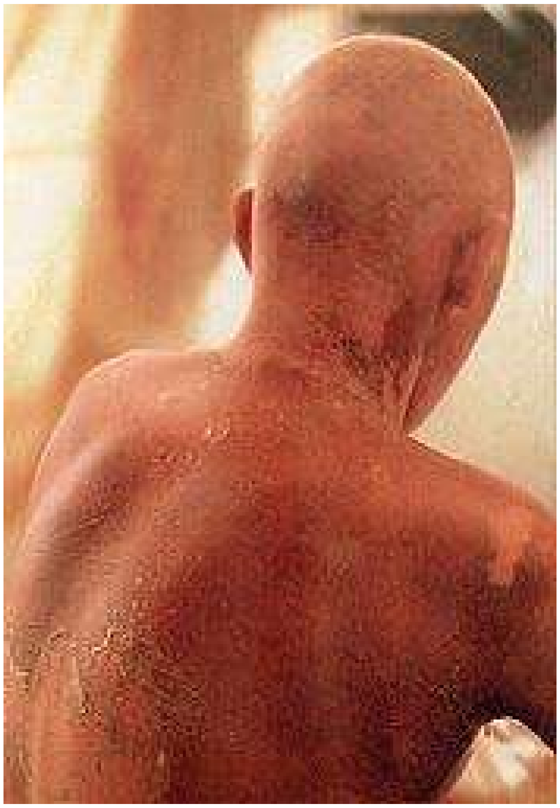


Fig 8 An example of a radiation burn

The dose at which half the exposed population would die in sixty days without medical treatment is called the **LD-50 dose** (where LD means Lethal Dose, and 50 meaning 50%). It is about 4 Sv for adults. The sixty-day period is sometimes explicitly identified, and the dose is then called the LD50/60 dose. In general, a number of different LD-50 doses can be specified, depending on the number of days, T, after which observations of death are cut off.

Because ionising radiation can damage the genetic material of virtually any cell, cancer can occur in many sites or tissues of the body. The actual effect depends in part on the route of exposure. For example, external radiation, such as X rays or gamma radiation, can affect DNA in blood forming cells or in many organs in ways that cause cancers of these organs' decades later. It should be noted that tissues vary in their sensitivity to radiation damage. For instance, muscles are less sensitive than bone marrows.

There are many pathways by which the body can be exposed to internal irradiation. Decay products of radon, which are present in an underground uranium mines, may be inhaled by miners and end up in their lungs. Particles of lead 210 (Pb-210) may be inhaled and deposited on the epithelial lining of the bronchi in the lung. A radiation dose from such exposure pathways increases the risk of lung cancer. In addition, soluble particles may be absorbed and distributed through the blood or lymph systems to other parts of the body. Some elements, such as radium, strontium, or iodine, tend to accumulate in certain organs. For example, iodine 131 delivers its principal ionising radiation dose to the thyroid gland, making that the most likely site of the resultant cancer. Iodine 131 is also used to combat thyroid cancer, since the emitted radiation destroys the cancerous cells along with the healthy ones. But when there is no disease in the thyroid, the radiation affects only healthy cells.

Fig 9 – An example of Iodine 131 used for in the treatment of cancer

In the case of Nuclear Density Meters the most significant hazard is the fact that they are portable and contain two radioactive sources. Although the machine is typically very robust, there is still a chance of dispersal of radioactive material in the event of an accident. If the probe is damaged in any way there is potential for leakage of the gamma source (which can be indicated by way of a wipe test). In the event of a fire there is significant inhalation risk especially if the Am-241:Be source is damaged in the process.

2.4 Personal dose assessment (radiation monitoring)

Dosimetry (measurement of the dose to an individual) should be required if the expected dose is 10% or more of the allowed dose. Proper use of a NDM will result in a dose that represents a fraction of the allowed dose. Some regulatory agencies take the position that it may be exceeded if improperly used and thus require dosimetry. Dosimetry is also used for long term legal protection to the licensee.

In this case a user may be requested to wear a Thermoluminescent Dosimetry (TLD) arrangement or a film badge while using the equipment (refer fig 18). Thermoluminescent (TL) means emitting light when heated. We can briefly describe the mechanism of TL as follows:-

When a strong energy source (such as ionizing radiation) hits a TL material, electrons are freed from some atoms and moved to other parts of the material, leaving behind "holes" of positive charge. Subsequently when the TL material is heated, the electrons and the "holes" re-combine, and release the extra energy in the form of light. The light intensity can be measured, and related to the amount of energy initially absorbed through exposure to the energy source.

The blue box issued to radiation workers is a plastic casing that holds chips or discs of TL material used as a dosimeter (i.e. TLD), and some metal foil to filter the radiation to be recorded. After the designated monitoring period, the TLD is collected and read by a TLD reader which can heat up the TLD, detect the resulting light emission, and calculate the radiation exposure to the person wearing that particular TLD. The TLD may be reused after a controlled heating procedure that completely recombines all "electron-hole" pairs, and restores the TLD to the original condition.

A Thermoluminescent Dosimeter (TLD) as worn on a lab coat

Fig 10 An example of a TLD unit.

The dosimeter used most often is the film badge (refer fig. 19), made up of two small x-ray films enclosed within a light-tight envelope and plastic holder. The badge is worn on the trunk of the body, usually at waist level or on the collar. Photographic film in the form of thin sheets with different thicknesses of emulsions applied to it.

The emulsion consists of small silver halide crystals embedded in a gelatine matrix. When the badge is exposed to radiation, energy is transferred to the emulsion causing silver ions to cluster together. These silver clumps are called latent image centres.

In NZ there can be two methods of personal dosimetry. One option uses the film badges as indicated below in fig 19 and these are available in yellow or blue options. The yellow option is used in specific medical applications while the blue option is for a more general application.

Also available, and more popular, is TLD in the form of ring dosimeters. These are worn on the finger of an individual especially technicians involved with the servicing of shielded radiation sources.

Fig 11 Examples of film badges and TLD ring dosimeters as used in NZ.

As far as NDM’s go it is considered that any user who is not exposed to the unshielded source will not receive a dose that warrants monitoring. However, in the case of routine maintenance of the cavity, some exposure to the unshielded is source is likely and this could warrant personal monitoring. Your Radiation Safety Plan should indicate your companies policy with regards to monitoring and you may be required to ‘prove’ to the Office of Radiation Safety (ORS) if it is necessary, usually by way of literature from the manufacturer or by undergoing a personal monitoring programme.

Section 3 Practical Radiation Protection

3.1 ICRP system of protection

The International Commission on Radiological Protection (ICRP) has over the last 60 years published recommendations for protection against ionising radiations. Adoption of these recommendations by governments has resulted in widespread uniformity of radiation protection practice worldwide.

The basic principles of radiation protection formulated by the ICRP are summed up by the following words.

- *Justification*
- *Optimisation*
- *Limitation*

Any human activity that results in an increase in the overall exposure to radiation, either an increase in the exposure to an individual or an increase in the number of individuals exposed, the Commission terms a ‘practice’.

3.2 Justification

The principle of justification requires that no practice be undertaken unless the benefits outweigh the associated risk or harm.

Radiation exposure may be only one of a number of risks and harms associated with a practice and all must be evaluated before the practice is approved.

For example, if NZ’s current power generation schemes proved to be insufficient or too expensive, then it may be necessary to implement nuclear power. If this was the case then the radiological consequences taken into account would include all discharges of radioactivity to the environment and the doses received by the workers in the industry. On top of this would be the potential for reactor accidents of various intensities and the also the disposal of radioactive wastes.

A comparison would need to be made with the consequence of alternative methods of energy production. For example if we look at coal-fired power stations we encounter numerous environmental, and health and safety issues. Coal–fired stations (e.g. Huntly) produce large volumes of waste which has to be disposed of somehow. There is also potential for natural radiation from the coal and coal miners can suffer occupational diseases. The burning of coal produces carbon dioxide and we must consider the potential impact of this greenhouse gas on the environment.

Fig 12 Huntly Power Station. Coal and gas fired

Vs.

Fig 13 A Nuclear Power Plant

Strategic and economic factors would also need to be considered. These may include security, availability and reserves of various fuels, the construction and operation of such a plant, and also finding staff and personnel that would be willing to work in this environment. This is the extreme end of the scale so plenty of consideration would have to be applied. It is likely that nuclear power has been considered in NZ, but at this stage the current energy production schemes and consequent energy demands of the country are suitable for our current population.

At the other end of the scale we could consider the risks vs benefits of taking an X-ray to determine if a bone is damaged. The benefits in a situation like this would generally outweigh the risk associated with the exposure to the X-rays. Therefore in a case like this it is easy to justify the practice.

As is the case with sealed radioactive sources, the benefit of obtaining good quality results generally outweighs the risks associated with its use.

3.3 Optimisation

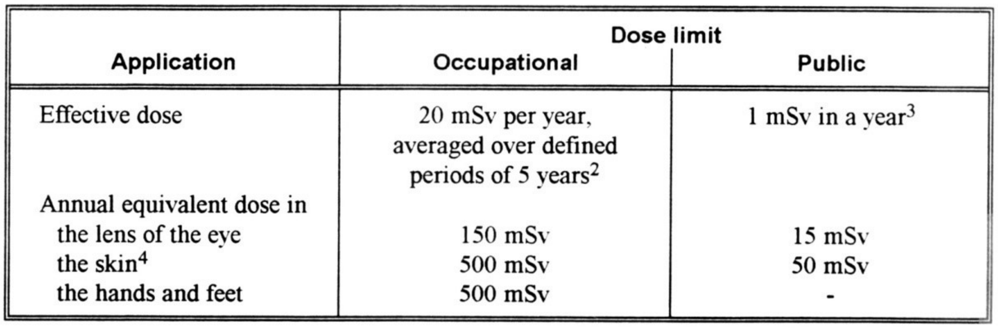
Optimisation requires that the practice be conducted in such a way that the net benefit is maximised. Risks and doses cannot be avoided altogether but are to be kept **‘as low as reasonably achievable’ (ALARA)**. Social and economic circumstances have to be taken into consideration so that absurd lengths are not required to reduce an already low dose or risk.

To achieve optimisation all consequences must be quantified and weighted. It is relatively easy to quantify the radiological and economic consequences. Social consequences may present much greater difficulties. Dose constraints and exposure risk constraints are important features of optimisation. From a study of well-managed similar practices the likely dose to an individual can be assessed and this can be used as a guide when considering a similar practice. With risk constraints the probability of the situation giving rise to the exposure as well as the detriment associated with that exposure must be taken into account.

If we apply this principle to sealed radioactive sources then ‘optimisation’ reflects best practice use of the gauge in all aspects from storage, transport and efficient operation.

3.4 Limitation

The commission has established a set of dose limits above which doses are regarded as unacceptable.



Application	Dose limit	
	Occupational	Public
Effective dose	20 mSv per year, averaged over defined periods of 5 years[2]	1 mSv in a year[3]
Annual equivalent dose in		
the lens of the eye	150 mSv	15 mSv
the skin[4]	500 mSv	50 mSv
the hands and feet	500 mSv	-

Fig 14 ICRP dose limits

3.5 Practical radiation protection

We are going to look at three factors, which can be used to influence the total radiation dose received in radiation work with gamma and X-ray sources. These are:-

- ***Time*** of exposure
- ***Distance*** from source
- ***Shielding*** extent and availability

Let's look at these in some more detail.

3.5 Time

This is a basic principle that basically states that the more time you are exposed to the radiation then the greater the dose. (Remember that the damaging effects of radiation can accumulate in the human body).

3.6 Distance

If the source is a point source (like we may find in NDM's) then the well-known **inverse square law** applies. This means that the intensity will be inversely proportional to the square of the distance from the source. This can be represented as:-

$$Y \propto 1/\chi^2$$

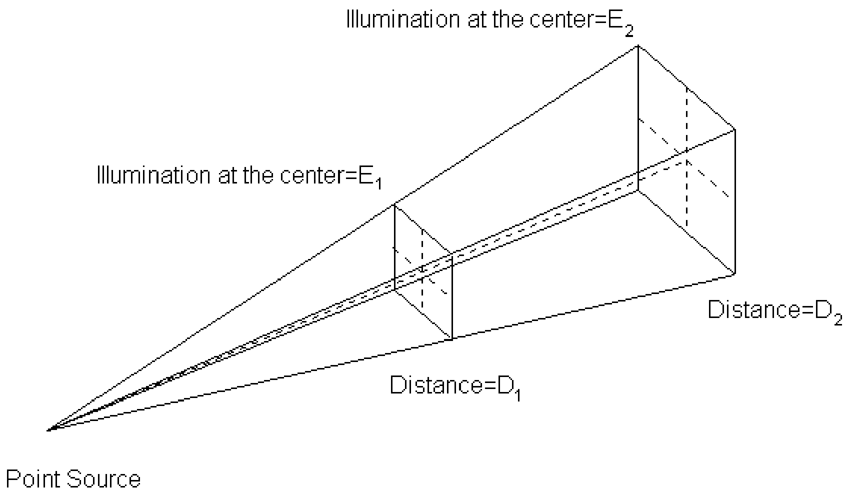


Fig 15 The Inverse Square law

3.7 Shielding

In some situations it may not be suitable to reduce the radiation intensity through distance. If this is the case then suitable attenuating material should be placed between the source and the personnel. This is the principle of shielding, and can be likened to a radiologist wearing protective clothing that contains lead. The lead present in the garments will provide suitable shielding for X-rays. The thickness and type of shielding will depend on the type and energy of the radiation. We should remember here that alpha radiation is not considered to be an external radiation hazard since its penetration depth is less than the thickness of a piece of paper.

Fig 16 Portable x-ray shielding

As far as beta radiation is concerned, there is generally no great difficulty in completely absorbing the radiation. The shielding thickness which is necessary to completely absorb a given beta radiation decreases with increasing density.

Materials of high density such as lead, depleted uranium, tungsten, are best suited for shields against gamma radiation. For quick estimates of shielding requirements half value or tenth value thickness of these materials are employed in computations. Very thick concrete walls are often incorporated in buildings as a radiation shield. Although concrete is less effective than lead, it is cheaper and can be used in substantial thicknesses to compensate.

Section 4 Accidents Involving Radioactive Material

Believe it or not every year the ORS and indeed the IAEA are alerted to incidents involving sealed radioactive sources in industrial gauging applications, including NDM's. At the root of most of these incidents is either a non-existent radiation safety plan or one that is simply not adhered too. This can lead to sources being 'lost' or simply forgotten about which increases the potential of sources falling into the wrong hands. One must consider at this point that ALL sources can potentially be dangerous if handled incorrectly by either exposure or ingestion.

Another concern with these 'orphaned' sources is their inclusion in scrap metal. This has occurred many times across the world and the likelihood of mass contamination could increase exponentially. This is certainly the case with a well-documented radiation incident that occurred in 1987 in Goiānia (Brazil).

4.1 Goiānia - 1987

Essentially a large ^{137}Cs source that was used in teletherapy (treatment of cancer) fell into the wrong hands which resulted in the death of 4 people and the potential contamination of thousands. The bullet points below are a timeline of events and some conclusions follow.

- The clinic was initially built in 1971 and a ^{137}Cs teletherapy unit was purchased. This was replaced in 1978 by a far more modern unit using ^{60}Co.
- In December of 1985 the clinic was moved along with the ^{60}Co device to another location but the ^{137}Cs device was left in the old 'radiation room' and basically forgotten. As of Jan 1987 there was no security posted at the old clinic.
- During this time the building became residence to some of the city's homeless.
- On the 13th of Sept 1987 two people removed the lead cylinders containing the radioactive source and took them off site. As the story goes they spent the next few days trying to hammer open the device but to no avail. These individuals would have received massive doses.
- Sept 16th, the iridium window was eventually broken and the culprits received massive doses of radiation as they observed the 'beautiful blue light' coming from the device.
- Sept 17th, the cylinders were sold to a local junk yard for a measly sum equivalent to $US25 at the time. The junk yard owner was intrigued by this amazing substance that had a blue glow and intended to make a ring for his wife out of the material. G'warn ma son..!

- Sept 23rd, the junk yard owner is able to damage the source to such an extent that he has managed to observe the source in its powdered form (Caesium Chloride).
- By now people had become sick with acute radiation syndromes (vomiting, nausea, diarrhoea etc).
- Sept 24th, the brother of the junk yard owner took some of this magical blue powder home to his 6 year old daughter and proceeded to rub some of this substance onto a concrete floor. The young girl (and the family dog) received very large doses of radiation from this powder and she died about a month later. She was buried in a lead coffin that was encased in concrete.
- Two other brothers also took some of the material home with them and soon became ill.
- Sept 28th, the wife of the junk yard owner had one of their workers take the lead cylinders to a local authority who confirmed its contents. She had suspected for a few days that the 'blue substance' was making her family sick.
- Once the authorities were aware of this a massive investigation began that involved the assessment of around 100,000 people of which 244 were contaminated.

Conclusions from this incident:

- The source was effectively 'lost' or forgotten which directly led to this incident.
- This highlights the 'cradle to grave' logging system for all sources
- By falling into the wrong hands the source could have been included in recycled metal. The consequences of this are the potential contamination of many metallic products. Also known as 'Hot Metal'.
- The lack of security allowed for the uplift of the device

Fig 17 (left) is an example of damaged teletherapy heads. Fig 2 (right) shows some of the decontamination work undertaken in Goiānia in 1987

4.2 Chernobyl - 1986

The Chernobyl disaster was a nuclear reactor accident in the Chernobyl Nuclear Power Plant in the Soviet Union. It was the worst nuclear power plant disaster ever (until Fukushima in March 2011) and the only level 7 instance on the International Nuclear Event Scale. It resulted in a severe release of radioactivity into the environment following a massive power excursion which destroyed the reactor. Two people died in the initial steam explosion, but most deaths from the accident were attributed to radiation.

Fig 18 Chernobyl Power Plant

On 26 April 1986 at 01:23:45 a.m. reactor number four at the Chernobyl plant, near Pripyat in the Ukrainian Soviet Socialist Republic, exploded. Further explosions and the resulting fire sent a plume of highly radioactive fallout into the atmosphere and over an extensive geographical area. Four hundred times more fallout was released than had been by the atomic bombing of Hiroshima.

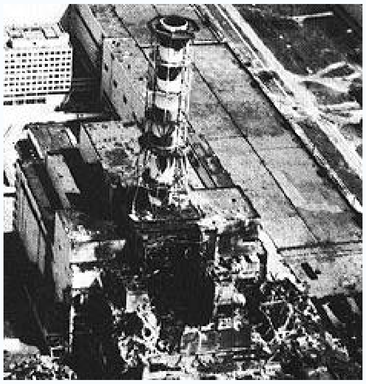


Fig 19 Chernobyl after the explosion

The plume drifted over extensive parts of the western Soviet Union, Eastern Europe, Western Europe, Northern Europe, and eastern North America. Large areas in Ukraine, Belarus, and Russia were badly contaminated, resulting in the evacuation and resettlement of over 336,000 people. According to official post-Soviet data, about 60% of the radioactive fallout landed in Belarus.

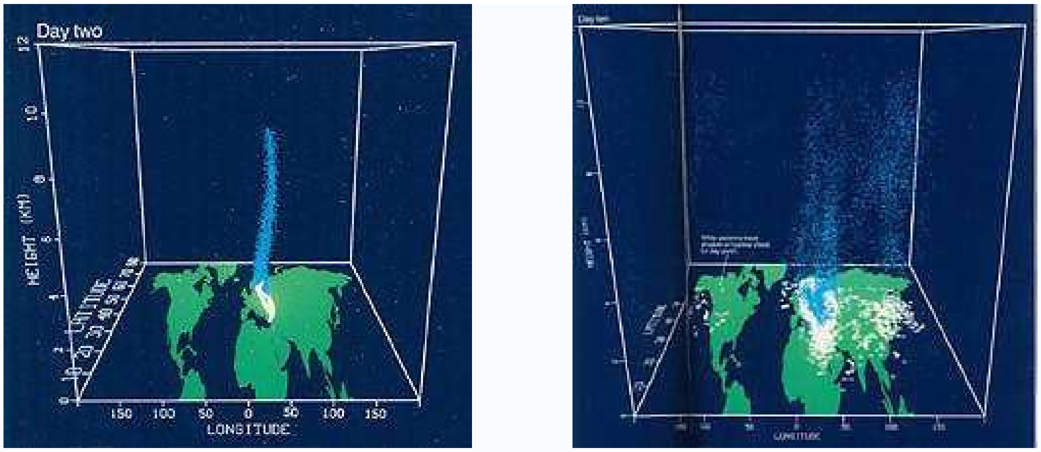


Fig 20 (left) an image depicting the fallout plume after day 2, and on the right the extent of the fallout (white) after day 5

The accident raised concerns about the safety of the Soviet nuclear power industry, slowing its expansion for a few years, while forcing the Soviet government to become less secretive. The now-independent countries of Russia, Ukraine, and Belarus have been burdened with the continuing and substantial decontamination and health care costs of the Chernobyl accident. It is difficult to accurately tell the number of deaths caused by the events at Chernobyl, as the Soviet-era cover-up made it difficult to track down victims. Lists were incomplete, and Soviet authorities later forbade doctors to cite "radiation" on death certificates.

The overall cost of the disaster is estimated at $USD200 billion, taking inflation into account. This places the Chernobyl disaster as the costliest disaster in modern history.

The 2005 report prepared by the Chernobyl Forum, led by the International Atomic Energy Agency (IAEA) and World Health Organization (WHO), attributed 56 direct deaths (47 accident workers, and nine children with thyroid cancer), and estimated that there may be 4,000 extra cancer deaths among the approximately 600,000 most highly exposed people. Although the Chernobyl Exclusion Zone and certain limited areas remain off limits, the majority of affected areas are now considered safe for settlement and economic activity.

4.3 Incidents in NZ

Although a major incident similar to what occurred in Brazil is unlikely to happen in NZ, the potential for orphaned sources in industry is quite high. A number of incidents involving fire have occurred in NZ and have resulted in the lead shielding melting away from the source. Naturally this will leave the source fully exposed and therefore potentially dangerous. Pertinent to the NZ Civil Industry is the likelihood of NDM's being damaged by heavy vehicles while on site, and also fire. It has happened many times in the past and will no doubt happen in the future. Any user of an NDM should be made well aware of the potential hazards of such accidents and be properly trained and regularly audited in emergency procedures. Accidents such as these should be taken very seriously and your Radiation Safety Plan should therefore include provisions for such events. Emergency services also need to be aware of these hazards by a company specific emergency evacuation plan which will indicate the presence of dangerous goods items, including radioactive devices.

Mechanical damage through other avenues is also a possibility and your Radiation Safety Plan should once again have measures in place to deal with this should it happen. Such incidents may include damage by forklifts and other heavy machinery operating in the vicinity. An awareness of the 'trefoil' radiation sign is important to these staff an indeed anyone else who may have access to the area (including public) and they must be inducted against the appropriate hazards.

Your Managing Entity (ME) needs to outline the relevant contents of the Radiation Safety Plan and includes 'local rules' which are specific to the ME. Any incident that does occur has to be dealt with properly and in such a way that the dispersal of radioactive material must be minimized. This must be documented in your Radiation Safety Plan.

Fig 21 Some examples of sealed radioactive sources used for industrial gauging. The device on the left is an in-line density gauge and is contained in a bright yellow steel-encased lead shield. The item on the right uses a ^{241}Am source to check product compliance in the beverage industry

Section 5 Safe Use of NDM’s and other sealed radioactive materials

5.1 The sources

The first thing we must consider is your device may carry up to two separate sources, and this next section will focus on a typical ‘Nuclear Density Meter’ or NDM, that is used widely in civil construction. The principles of measurement and radionuclide encapsulation is the same for all industrial gauges using radioactive material. One is Americium 241 (Am-241) which is mixed with Beryllium and further encapsulated in stainless steel. This construction allows for the ‘knock-off’ of fast neutrons from the source. It is these neutrons that penetrate the soil/material in search of hydrogen (H+), where they will thermalise in its presence, thus slowing the neutrons down and enabling them to be picked up by a slow neutron detector.

The gamma source in a NDM is Caesium 137 (Cs-137) and is well shielded in the off position (or commonly referred to as the ‘safe’ position). When in this position the sealed source is surrounded by a tungsten shield which should eliminate any external radiation hazard. However, if the handle has not been set correctly, or the sliding shield has become blocked or obstructed then the source may be exposed somewhat. The handle adjustment on the NDM is critical not just for safety but also for accuracy; therefore time should be spent ensuring that the handle is seated properly, and that the metal block on the underside of the gauge completely covers the hole.

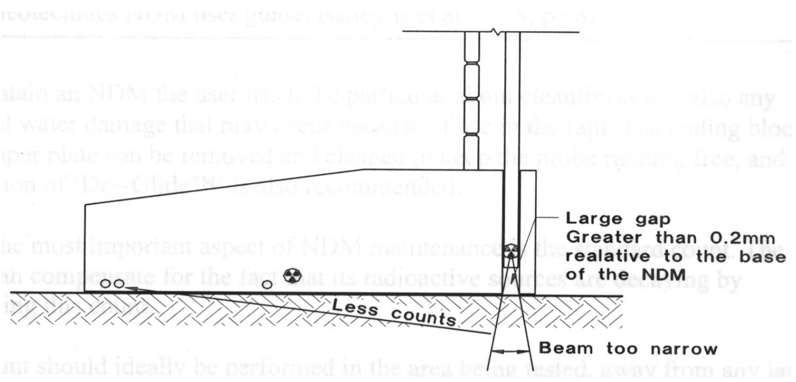


Fig 22 Incorrect position of the source handle. In this instance the probe is set too high therefore reducing the beam angle. This can be remedied by careful adjustments.

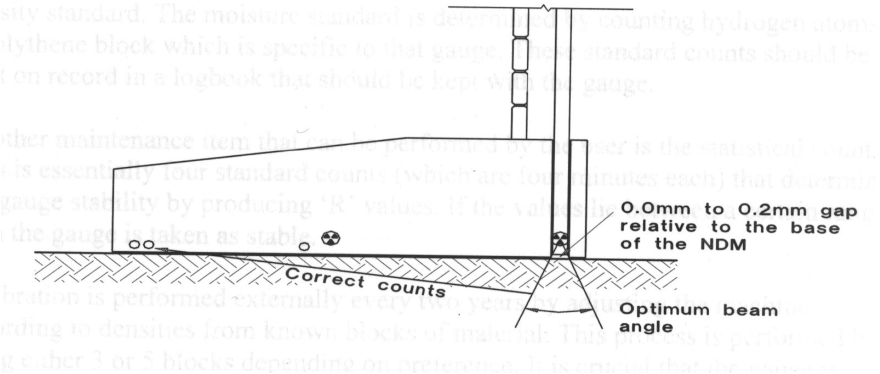


Fig 23 Correct handle position. This allows for the optimum beam angle.

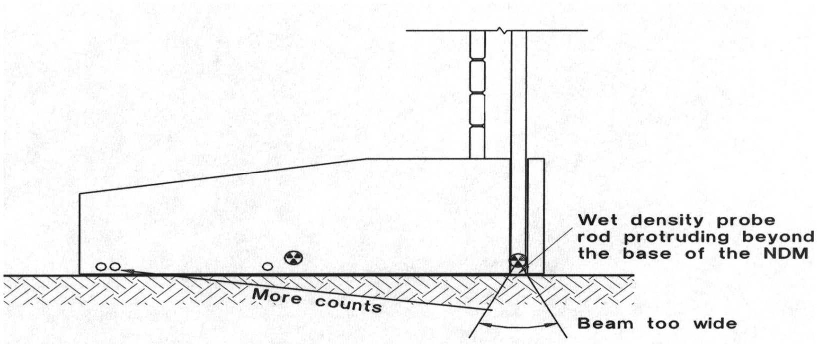


Fig 24 Incorrect handle position causing a wide beam.

5.2 The handle

Your NDM has a “SAFE” position which means the gauge is shielded and therefore safe. Any movement away from this position will move the source away from the shield.

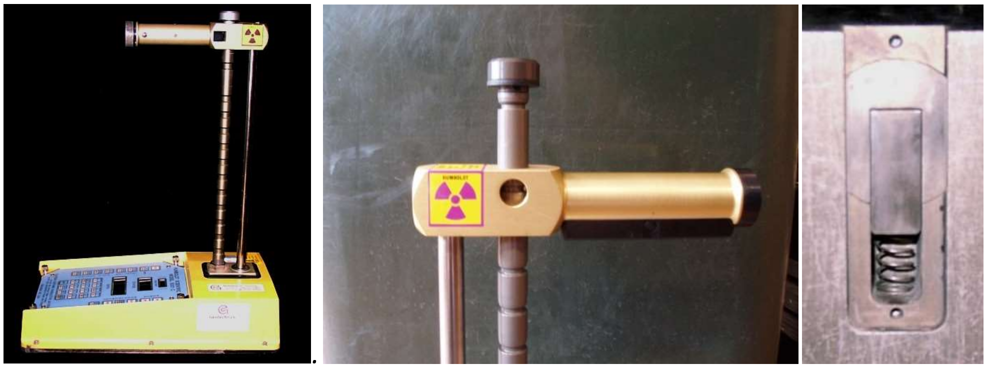


Fig 25 the picture on the left shows an NDM in “SAFE” position while the picture in the middle is the “BACKSCATTER” position and the source is therefore unshielded at this point. The picture on the right shows the sliding tungsten shield assembly once the bottom plate has been removed.

5.3 Wipe testing

The principle of wipe testing is quite simple in all reality. A cotton bud is moistened with isopropyl alcohol (IPA), water, or can even be left dry. The person who is performing the test will wear rubber gloves and will rub the cotton bud over the scraper ring on the underside of the gauge and another cotton bud over the Am/Be source on the inside of the NDM. Any particulate material will be picked up and this can be analysed for the presence of radioactive material which may indicative of mechanical damage.

The cotton bud is then sealed in a plastic bag that is supplied and sent to the ORS for analysis. The ORS will then use a device called a Geiger-Muller counter to test for radioactivity. They will typically test the bud and then turn it 90 degrees and then test again. This will be repeated until all 360 degrees of the bud has been tested. The value reported would be the highest value obtained by the ORS.

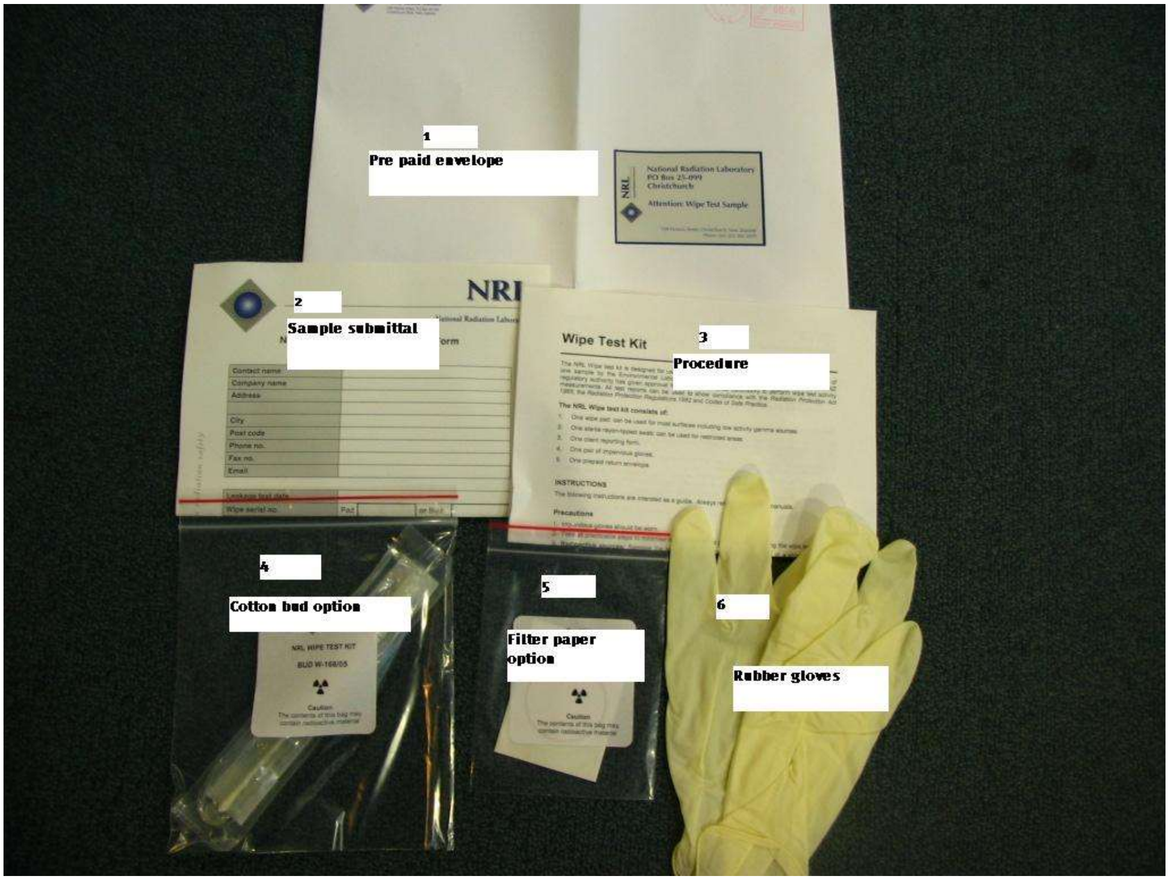


Fig 26 Example of a wipe test kit. This standard kit consists of the following items:

- Pre-paid A4 envelope
- Sample submittal form
- Wipe test procedure
- Cotton bud
- Filter paper
- Rubber gloves

It is mandatory in NZ to perform wipe tests on all sealed radioactive sources used in industry. A wipe test must be performed if:

- The gauge is involved in an accident (this must be included in your Radiation Safety Plan)
- Once the gauge reaches 10 years old (10 years from the date of manufacture)
- And then every 2 years (this is usually done as part of the biannual calibration)

Section 6 Legislative requirements

6.1 Licensing requirements

In NZ the safe use of radioactive materials is governed by the following legislation:-

The Radiation Safety Act 2016
The Radiation Safety Regulations 2016

This legislation is administered by the Ministry of Health though the Office of Radiation Safety, ORS.

6.1.1 Buying and selling radioactive material

No person may acquire or sell radioactive material unless prior consent has been given by the ORS. Without this consent the NZ Customs Service does not permit importation, If the radioactive material is to be under the control of a person holding an appropriate license, or if it less than the activity exempted from licensing requirements, an “Authorisation to Import Radioactive Material” will be issued and should be presented to customs officers when clearing the radioactive material. Applications for these authorisations should preferably be signed by a licensee, but in any case should be clear as to who will be the licensee responsible for the source.

6.1.2 License holders

The radiation protection act prohibits the use of radioactive material except for a person who holds a current license under the act or by a person acting under their supervision or instructions.

Under the regulations, it is the responsibility of every owner of radioactive materials to ensure that all radioactive materials he/she owns which exceed the exempt activities are under the control of an appropriate licensee.

Authority to grant licenses has been delegated to the Director of the ORS and license application forms are available from them. An applicant for a license must show a certain standard of knowledge and competence to use radioactive materials safely and also has the access to suitable safety equipment. The use of radioactive materials authorised by the license will be restricted to a specified purpose or purposes, and may be made subject to specified conditions. **The granting of a license places full legal responsibility for safe use while under the license**. Many sealed radioactive sources used in industry are of low activity, so typically the license holder may only have to deal with issues covering the safe custody of the unit. In other cases, however, the use of radioactive sources may present significant potential hazards. As the licensee is responsible for the safe use of radioactive material he/she must have sufficient authority to ensure that all persons working under their license follow their instructions relating to safety.

6.1.3 Licenses for large organisations

In the case of a large organisation with geographical spread, more than one source and/or use licenses may be required depending on your application. In such cases, the regulations require Managing Entities (ME's) to appoint suitable Radiation Safety Officers (RSO's) that can act quickly and efficiently in the case of an emergency. Therefore, it is recommended that if not done so already, consult with the ORS regarding your precise situation.

However, best practice shows us that most, if not all ME's appoint a RSO at each depot, or branch where a radioactive/irradiating apparatus device is used, stored, hired from or to. The idea being that the ME should do their best to make sure that devices do not become orphaned, lost, stolen, and put processes and staff in place appropriately to manage any risks.

The ORS have a document that should be made available to anyone using the device(s). These are the Codes of Practice and associated documents and are documents outlining the areas that can be audited if need be. Any ME, RSO and personnel working under the RSO should make themselves familiar with the Code. A copy of the Code should also be kept in in a common place for quick reference if need be.

The Code(s) cover the following: -

- Registers and records requirements
- Safety management, including storage, labelling, accident prevention, maintenance and servicing, wipe testing (not for X Ray), safety audits, radiation monitoring, radiation surveying, training, hazard mitigation etc
- Operator safety and local rules
- Glossary of terms and definitions

Section 7 Licensee Responsibilities

7.1 The Radiation Safety Plan (RSP, aka Radiation Management Plan)

The Radiation Safety Plan or RSP is a company specific document that details relevant information about the sealed radioactive source(s) and/or irradiating apparatus (e.g. X-ray generating devices). It covers a wide range of areas that are covered below, and it is strongly urged that this document be maintained by the RSO in conjunction with the ME, and this document will be audited on behalf of the ORS by ESR Enforcement Officers. All users of the devices should be aware of the RSP and indeed should read and agree to this document before using any sealed radioactive source, or X Ray device.

Fig 27 RSP's can either be hardcopy or electronic as long as the document is readily accessible to all users

7.1.1 Contents of the RSP

The RSP can either be electronic or hard copy, but must be readily available to all users and associated personnel. A typical RSP will consist of 8 sections, although some sections will have limited information in them due to the nature of your business.

In essence your RSP should have information regarding the following: -

1. Responsibilities and authorisation – Outlining who has overall responsibility of the device(s) and an account of authorised users who by way of the RSO. It is recommended that all users sign this section of the RSP to confirm that they will comply with the RSP.
2. Irradiating apparatus & radioactive materials records – This section focuses on the need for a 'cradle to grave' logging system that maintains an auditable trail. It essentially contains information on each device owned by the company or facility at which the RSP applies. It will also outline its storage

location, calibration and service information and wipe test results (not for X Ray). For sources that are transported away from the facility (as is always the case with portable gauges) there must be a logging system that details the location of the gauge at any one time.

3. Radiation safety training – A section that contains training records for RSO's, authorised users and other associated personnel. There must also be written protocols that highlight your companies policy with regards to ongoing and refresher training.
4. Radiation safety audit procedures – You must ensure that there are systems in place that allow for internal audits to be conducted on a routine basis, typically at least once per year. These audits should cover compliance with the Code, and for users should also cover storage and transportation if required. Audit reports should be kept on record and any corrective actions will need to be amended and documented.
5. Local rules for radiation use – These are written (and therefore company specific) instructions for the use/storage/transport of the device to ensure safety to everyone involved. It is advisable that a policy is written (if not already) regarding potentially pregnant users.
6. Emergency procedures – you will need to detail the procedures that must be followed in the case of an emergency such as fire or earthquake. It is also required that all radioactive materials are indicated in emergency evacuation plans and emergency services are notified.
7. Incidents and accidents – Any incident that has the potential to cause levels of radiation exceeding what would be normal has to be reported to the RSO who will conduct an investigation. You must write company specific accident procedures with instructions on what to do and important phone numbers in case of an accident. Any incidents that do occur should be investigated in such a way that changes to standard procedures will decrease the chance of a repeat occurrence.
8. Personal monitoring – This section should contain a company policy on the personal monitoring of users of radioactive material/irradiating apparatus. In some cases personal monitoring will not be required due to very low exposures, but this must be proven in the RSP by way of either manufacturer documentation or by evidence of previous personal monitoring programs.

7.2 Storage, security, transportation and accident procedures

Most of the gauges that are used in industrial gauging applications are installed on-site and do not need to be moved around unless for servicing etc. However some devices are portable and are always being used away from the base. This means that we need to be aware of the storage, security and transportation requirements.

7.2.1 Storage

A ‘storage facility’ complies with the following criteria:

- Free of other Dangerous Goods (DG’s) items
- Lockable facility where the access to the area is controlled by the RSO and ME
- A warning sign (standard radioactive ‘trefoil’ sign) will be present on the facilities door, and other doors into the facility, and HAZMAT boards if applicable
- The facility is sufficiently shielded or remote from occupied areas so that dose rates do not exceed 0.3 mSv per year. Instantaneous dose rates of less than 15 micro-sieverts/hr
- The facility must always be available when the NDM is not is use
- When a device is temporarily stored on location (i.e. on site), it shall be kept in a locked building or vehicle that is under the control of the RSO.

Fig 28 correct signage for a storage facility containing radioactive materials

7.2.2 Security

It is important that the device is kept in a secure location whether it is stored on site or at the office. The storage packages that contain the devices should have lockable latches on it. These should be used when the device is not in use. The storage facility will also have a lock on it, where the key holders should be the RSO, and any other personnel authorised by the RSO. The ME must do all that is possible to make sure the devices are as secure as possible, and mitigate all they can against a malicious act.

Fig 29 When the gauge is unattended it should be locked in its type A package/storage package. Most locks on these packages allow you to use a padlock or have key locks built in to them

7.2.3 Transportation

All transport of sealed radioactive sources must comply with the International Atomic Energy Agency (IAEA) Regulations for the Safe Transport of Radioactive Materials and Land Transport Rule: Dangerous Goods 2005.

In short the transport of sealed sources can be summed up by the following:

1. Correct transport container is used, e.g Type A
2. Vehicle placards, front and rear (sealed sources only)
3. Dangerous Goods documentation
4. Accident procedures
5. Logging systems managed by the ME and RSO that always monitor the location of the devices

7.2.3.1 Packaging, labelling and the Type A Package

All transport and storage of the device must include its "Type A Package". This vessel (usually the large plastic yellow box) is internationally recognised for the transport of radioactive devices of this nature. It is lockable, robust and has the correct labelling on both the front and rear of the package. Fig 29 shows the accepted labels for most sealed radioactive materials in NZ. Please note that the contents and the Transport Index (TI) is relevant to your device.

Fig 29 Current labelling requirements for the NDM. Note the UN number, transport index and contents

7.2.3.2 Vehicle placards

"RADIOACTIVE" dangerous goods placards must be displayed on any vehicle carrying a Type A package. The appropriate placard is shown below.

Fig 30 A placard like this is displayed on the vehicle during transit

The placard must be at least 250mm x 250mm square. The upper half of the diamond must be coloured yellow, and the lower half white.

It is required that these placards are visible from both the front and rear of the vehicle and a good reference is the 25m rule. If you can see the placards on the front and rear of the vehicle from 25m in daylight then the signage complies. This means that the placards need to be placed vertically, and as far forward and rearward as possible.

7.2.3.3 Dangerous Goods (DG) documentation

All transport of the device must be accompanied by the relevant travel documents and these must be placed in the cab of the vehicle, **although in NZ it is common to put these documents in the drivers' door pocket.**

The DG documents for sealed source transport fall into two parts; Shippers Declaration (Candy Form) and 'Special Form' certificates. The Shippers Declaration is a red-striped-edge form that contains information on the sender and receivers address (usually the same for most device transport), the package, and its contents. It should also contain the words 'Tools of Trade' in the Transport Consignment box found in the top right-hand corner, as this allows us to transport the device without the need for a DG endorsement on our driving license.

Special form certificates are specific to the make and model of the gauge and can usually be downloaded from the manufacturer's website. Your commercial agent can also help in the production of these documents. They outline the construction and nature of the radioactive sources in the device (hence the term 'Special form').

It is important that all DG documentation is the original copy and not a photocopy, or as supplied by email (pdf usually) by the commercial agents.

7.2.3.4 Accident procedures

You should include a company specific Accident procedure with the travel documents (as an appendix). An accident procedure can also be found on the rear of the standard Candy form.

The ORS states that you should assume that damage has occurred to the encapsulated source after every accident event. From here it is mandatory for the RSO to perform a wipe test to confirm any leakage.

The accident procedure is outlined below:-

- Retract the source rod into its closed position if possible, if this was extended at the time of the accident

- The Regulatory Authority (ORS or MoH) should be advised of the accident, and the commercial agent should also be contacted for advice.

- Establish a clear zone of about 3m radius around the meter. Mark the area with cones if available.

- The RSO responsible for the meter at the time should be called if not on site already.

- A wipe test is performed as soon as possible to ascertain any damage to the device (sealed radioactive only)

- Whether or not any release of radioactive material is indicated, the damaged instrument and any debris should be placed inside a large plastic bag and sealed with adhesive tape. In the absence of a plastic bag, it should be wrapped in a plastic sheet, and sealed as best as possible with adhesive tape. A warning label should be attached to the package. The external radiation dose received in the short time expected for the wrapping procedure is of much less concern than the need to contain any radioactive contamination, no matter how unlikely its occurrence. If the source rod is jammed outside of the unit, then it should be left as so in the plastic packaging. Attach a label to the packaging that indicates the contents, and also indicates the position of the probe.

- The wrapped instrument should then be transferred to a safe and secure place.

Before further transportation can be undertaken, the packaging should be checked that it complies with the transport regulations.

With this is mind it is a good idea to have all of this prepared and ready to use if need be. Some examples are below: -

- Wipe test kit

- A large plastic bag

- A roll of adhesive tape

- At least one warning label

- Phone numbers of the Regulatory Authority (ORS) and the commercial agent

- Instructions on a laminated sheet that outlines exactly what to do if an accident does occur.

7.2.3.5 Logging systems

All transport and storage of sealed sources must be accurately logged. The usual method in NZ is to have a logbook or similar in or near the storage facility that all users are aware of. The logbook must detail where the device is at all times (e.g. storage or site address), the reason (e.g. testing, calibration, service etc), and who has it. This logging system is crucial and it is recommended that you audit the people who frequently transport that gauge.

Section 8 Audits and the ORS

8.1 Internal audits and routine inspections

Safety procedures only work if everyone follows them, and record systems only work if they are kept up to date. It does not take much of a gap in a set of records before the record system becomes dysfunctional. Therefore the reason behind the safety audit (and any audit in general) is to check that these guidelines are being followed. The audit will then provide an opportunity to expose any weaknesses that the operator may have, and correct them there and then.

It should not be seen as a 'telling-off' session, but an opportunity to fine-tune the safe practices involved with owning and operating such devices.

The safety audit should be assigned to an individual at each establishment who should systematically work through the records for each meter and verify the compliance with the code.

By far the easiest way is to have a check list which covers all the necessary items in the Code. Each device should either be sighted in storage or verified as being with the person who has signed it out. All current entries in the user log must be verified as being correct. The audit should also cover the transportation and documentation related to the device. Anything that is found to be non-compliant should be addressed and documented.

8.2 Audits/Inspections on behalf of the ORS

Officers working on behalf of the ORS perform routine audits of ME's for radioactive material and Irradiating Apparatus to examine and discuss safety aspects of the work. Establishments using radioactive material of minor potential hazard will be visited infrequently, but if the potential hazards are significant, visits may be made more frequently. Any ME or RSO is welcome at any time to contact the ORS if they have any problem on radiation safety aspects of their work.

The officer may wish to inspect storage facilities and records to confirm that the code is being adhered to. Upon which the officer may make recommendations for improvements.

Any non-compliances raised by the Enforcement Officer will need to rectified in the mandated time frame, as per the conditions of the audit.

Section 9 Lost sources and Disposal

9.1 Lost sources

We have to consider that any lost source means that it cannot be traced. This can pose problems to the environment and the source may also end up in the wrong hands.

If you follow the simple regulations for storage and transportation then this should never be the case. If it is however, it is the licensee's responsibility to try and locate it straight away. The ORS must be notified of the loss within 7 days of the incident, and you should also advise them of the actions already taken.

9.2 Disposal

Whenever disposal of a source is considered, the ORS must be advised first. In NZ, there is not a facility as such that radioactive materials can be dumped. However the MoH can occasionally dispose of some sources.

It is recommended that the ME considers a disposal policy as part of any future purchases of similar devices, i.e. the Commercial agent will deal with the old device so long as you buy a new one.

Whatever the case you should never consider taking things into your own hands (i.e. dumping the source yourself) and you must always consult with the ORS.

9.2.1 Disposal of sealed radioactive sources

Sealed radioactive sources may be decommissioned for a number of reasons. They may be obsolete, damaged and uneconomic to repair, or just surplus to requirements. Because of the radioactive sources in a device, the owner is not at liberty to dispose of it at will or by just abandoning it.

If for any reason your device(s) are no longer required, then the owner has three options.

- **Option 1**

The meter can be held in storage under the control of the RSO. While this arrangement can continue indefinitely as long as there is a RSO responsible for it, there is a risk of the device being "forgotten". Therefore the ORS strongly recommend that it is sold or disposed of.

- **Option 2**

It may be sold or exported. If this is the case the ORS would have to grant consent for you to do this. By involving the ORS, source serial numbers and the master serial number can be traced at all times.

- **Option 3**

It may be disposed of as waste in an approved way. This will ultimately involve the original manufacturer of the unit and the export of the retired unit to them for decommissioning. Either way the ORS will still need to be advised of the intended disposal method so they can update serial number and owner records accordingly.

NOTES