

Industrial Radiation Safety Training for Intending Users

Level 2 Portable Density and Moisture Gauges

McKavanagh Engineering Services Pty Ltd

B08 Harbour City Central, 216 Harbour Rd, Mackay QLD 4740

ABN: 27 081 830 579

Email: office@mckeng.com.au

These notes have been developed for persons seeking to obtain a Use Licence Issued under the Radiation Safety Act 1999 for using a portable moisture density gauge.

This publication remains the property of McKavanagh Engineering Services Pty Ltd (MES) and must not be reproduced or copied, wholly or in part without written approval from MES.

INTRODUCTION

These course notes have been prepared specifically for persons wishing to obtain a licence to use portable moisture density gauges in Queensland.

RADIATION HEALTH CONTACT DETAILS
(including **EMERGENCY CONTACT**)

Radiation Health Unit

Queensland Department of Health

PO Box 2368, Fortitude Valley BC, Qld 4006

15 Butterfield St, Herston, Qld 4006

Telephone: +61 7 3328 9310

Radiation producing equipment has resulted in many benefits. These benefits range from the production of medical and industrial radiographs to the sterilisation of fragile medical equipment and the therapeutic treatment of cancer. However, this equipment and other radioactive devices with all their benefits, must be handled with care.
Specific safety rules associated with their use must be followed.
Careless operators could receive unnecessarily high doses. When a source is destroyed and contamination results, enormous costs are incurred in removing and disposing of contaminated material.

Compliance with these requirements will ensure that radioactive sources are always controlled by a competent user who can handle them safely.

Contents

CHAPTER 1: PROPERTIES OF IONISING RADIATION 5

1.1 Origin of Radiation 5

1.2 Types of Radiation 5

1.3 Properties of Radiation 6

1.4 Penetrating Power and Hazard of the Different Radiation Types 7

1.4 a Alpha particles: α 8

1.4 b Beta particles: β 9

1.4 c Gamma γ and X-rays 9

Neutrons 10

CHAPTER 2: RADIATION PROTECTION 11

Introduction 11

Radiation Units and Dose Levels 12

Background Radiation Levels 12

Damaging levels of Radiation 14

Contamination with Radioactive Materials: 16

Dose Limits in context of background radiation: 16

CHAPTER 3: RULES OF THUMB FOR EXTERNAL DOSE CALCULATIONS 17

Point Sources 17

Point source Cs^{137} gamma emitter 17

Point Am^{241}/Be neutron source 18

CHAPTER 4: SAFETY MEASURES WITH IONISING RADIATION AND RADIOACTIVE MATERIALS 20

Time of Exposure 20

Distance 21

Shielding 21

CHAPTER 5: WORKING RULES FOR USE OF PMDGs 22

Working Rules for Soil Density & Moisture Measurement 22

Personal Monitoring 23

Transport 23

Storage 24

Repairs & Maintenance 24

CHAPTER 6: EMERGENCY PROCEDURES 25

What is an emergency? 25

Emergency Procedure if PMDG obviously damaged 25

Emergency Procedure if PMDG not obviously damaged 26

Incident Reporting 26

Appendix 1 Emergency Contacts 27

Appendix 2 Wipe Testing 28

Appendix 3 Information from Troxler on Source Construction and Half Life: 29

Appendix 4 Radiation Measurement 30

Appendix 5 DRAAD for Portable Density and Moisture Gauges 31

Appendix 6 Extract from RPS C-1 32

Schedule A Dose limits for occupationally exposed persons 32

Appendix 7 Queensland Penalty Units 34

Notes on Penalties and Penalty Units 34

Table 1. Periodic Table of the Elements 35

Table 2. Table of the Isotopes 36

Table 3. Collisions to Thermalisation and other data for neutrons 37

Table 4. Radiation Profile for Troxler 3430 38

Table 5. Radiation Profile for Troxler 4640 39

TABLE 6: Relationships Between S.I. Units and Non-S.I. Units 40

References: 41

Document Control 41

CHAPTER 1: PROPERTIES OF IONISING RADIATION

1.1 Origin of Radiation

All of the high energy radiation discussed in this course is emitted by the nuclei of atoms, except for X-rays (X-rays are emitted by the atomic **electrons**, which orbit the nucleus). **Atoms** are the extremely small basic units which make up all substances, whether in solid, liquid or gaseous form. They are typically one ten-millionth of a millimetre in diameter. Each atom consists of a very small and dense, positively charged nucleus surrounded by a cloud of particles with negative electrical charge known as **electrons**. The **nucleus** itself contains two types of particles;

- **protons**, which have positive electrical charge and are about 2000 times as massive as the electrons in the surrounding cloud.
- **neutrons**, which have nearly the same mass as protons but no electrical charge.

This is the simplest model of the atom and the nucleus is shown in **Figure 1**

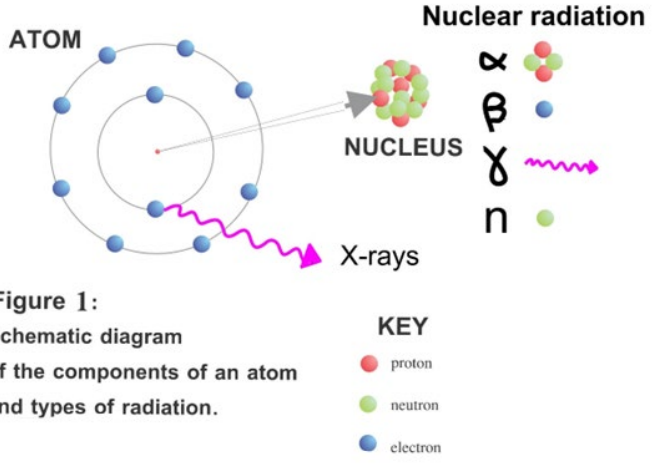


Figure 1: Schematic diagram of the components of an atom and types of radiation.

Certain types of atoms of most chemical elements have nuclei which have too much energy to be stable, and these nuclei can lower their energy by emitting high-energy particles or rays. The nuclei of such atoms are said to be **unstable** or **radioactive** and the atoms are called radioactive isotopes of the particular element. The particles or rays emitted by the nuclei are called nuclear radiation.

1.2 Types of Radiation

Four different types of nuclear radiation are commonly emitted by radioactive isotopes. These are:

- **Alpha particles α,** consisting of two protons and two neutrons bound together as shown in **Figure 2 (a)**. Alpha particles have a positive electrical charge.

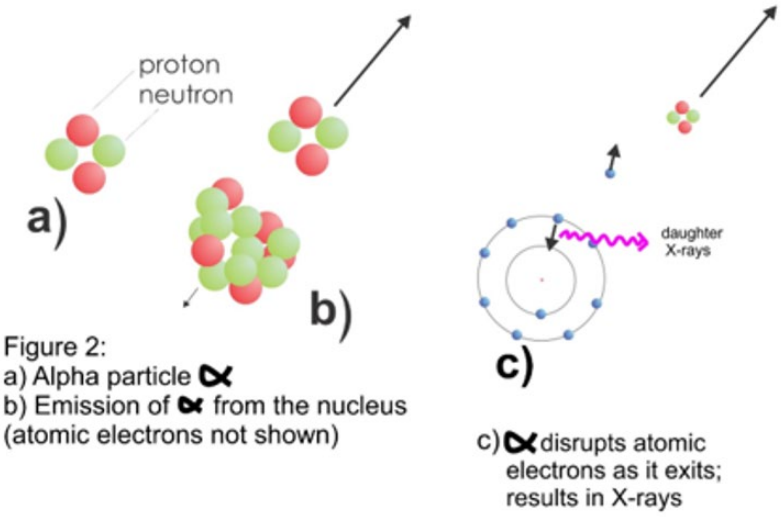


Figure 2:
a) Alpha particle ∝
b) Emission of ∝ from the nucleus (atomic electrons not shown)
c) ∝ disrupts atomic electrons as it exits; results in X-rays

- **Beta particles β,** which are in fact energetic electrons emitted from the nucleus at very high speeds, close to that of light. Since they are electrons, beta particles usually have a negative electrical charge.

- **Gamma rays γ**, which have a wave nature similar to radio waves, light and X-rays. They have a much higher energy than light and are extremely penetrating, which makes them particularly useful in Industrial applications.

- **Neutrons.** Under certain conditions, some types of radioactive isotopes will also emit neutrons. They are extremely penetrating because they have no electrical charge and are not affected by electrical charges in matter. Many materials exposed to neutrons can to some extent become radioactive or "activated" - even if not radioactive before. **This does not occur with alpha, beta and gamma radiation**. With the relatively small sources used in industry, the amount of neutron activation is so small it can only be detected by sensitive detectors and is not sufficient to cause changes that are measurably above background radiation.

1.3 Properties of Radiation

A **radiation source** of the type used in industrial applications will contain a very large number of atoms of a particular radioactive isotope such as Cesium 137 (Cs^{137}) or Americium 241 (Am^{241}). The large number of radioactive nuclei in the source gives rise to a continuous emission of radiation. This gradually becomes weaker with time as more and more nuclei emit their radiation. after which they become stable and are no longer radioactive. For a Cs^{137} source it takes 30 years for the level of activity to **Decay** to half its original value. This time is known as the **half life** of the isotope. The definition of **activity** is a radioactive disintegration per second and is measured in **Becquerels** (Bq)

For Am^{241}, the half-life is much longer at -430 years. These radioactive sources can present a hazard for very long periods of time and must be disposed of at the end of their useful working life by an **approved method**, such as to a waste storage facility here or overseas, or by recycling. The **working**

life refers to the method of source construction and is usually 15 years for the sealed sources used in soil density/moisture gauges (abbreviated as PMDGs). Thus, for Cs^{137}, the working life is determined by the source construction and not by the longer half-life. (See Appendix 3 for information from Troxler on half life and source construction).

Cs^{137}emits β particles and γ radiation, while Am^{241} emits α particles, followed by X-rays. However, the radioactive Am^{241} is intimately mixed with atoms of beryllium Be^{9}. This normally has a stable nucleus, but the α particles cause a nuclear reaction. This results in stable carbon, C^{12}, being formed, with the emission of a neutron in the process. This is shown schematically in **Figure 3**. The fast neutrons produced by this process are well suited to in-situ moisture measurement; Am^{241}/Be sources are used extensively for this purpose in a wide variety of situations, from foundations in civil engineering, to soil moisture in agriculture, through to "porosity logs" in coal and hydrocarbon exploration. You should also be aware that Am^{241} is the source of a radiation used in most household smoke detectors, so it is the most widely used isotopic source of Ionising radiation.

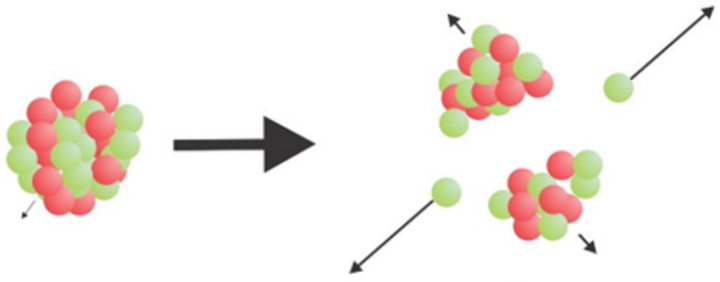


Figure 3: Spontaneous fission of a nucleus, showing release of 2 neutrons, and recoil of the fission daughter nucleii

A **Periodic Table** and a **Table of the Isotopes** are included for your information as Table 1 and 2. This information is sufficient to derive the decay equations of most industrial radioisotopes. Note also that there is another source of neutrons increasingly being used, Californium-252 (Cf^{252}). This has a relatively short half-life of 2.64 years, and is now used in some Troxler PMDGs, although not in Queensland at the time of this revision.

1.4 Penetrating Power and Hazard of the Different Radiation Types

The different types of radiation discussed in Section 1.3 differ considerably in their properties and, although they are **all** hazardous, the hazard is different in each case. We'll discuss each of these radiation types in turn.

The crucial damage produced by **all types** of radiation occurs by a process known as **ionisation**. In this process, an energetic radiation particle collides with one of the electrons in an atom in the material and knocks the electron out of the atomic cloud as shown in **Figure 4.**

The ionisation process leaves the atom with a nett electrical charge, and therefore very reactive. This affects the chemical reactions which occur in living tissue at the cellular level, particularly in DNA, resulting in the death or impairment of the cells. (Other objects such as metals, soils and rocks are not permanently damaged, but plastics and fibreglass are examples of materials that are.) If the ejected electron gains enough energy in the collision, it can also cause further ionisation.

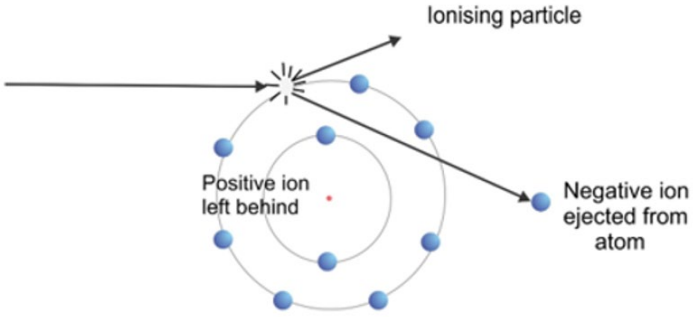


Figure 4: Schematic of the ionisation process. X-rays may also be produced.

1.4 a Alpha particles: α

These particles travel relatively slowly (about 10,000 km per second) because of their large mass. As a result, they do not penetrate very far into matter. About 70 mm of air, 0.8 mm of water, or 0.2 mm of lead are sufficient to completely stop or **shield against** α particles in the usual energy range in which they are emitted from the nuclei. The α particles produced by the Am^{241} source do not penetrate beyond the source capsule, (which is of a double welded stainless-steel construction), but must be considered for emergency purposes if the source encapsulation is breached.

The penetrating power of all types of radiation in soft body tissue is very similar to the penetration in water. For this reason, the α particles emitted by most α-emitting isotopes only just penetrate into, but not through, the dead layer of skin on the outside of the body. Alpha particles do not therefore present an **external** hazard. However, if a substance which emits α particles enter into the body, particularly by inhalation, this is **extremely** hazardous because these particles cause intense damage to living tissue over the short distance they travel before being stopped. All of the energy of the particle is transferred to the tissue over this short distance, so the ionisation damage is highly concentrated in the tissue immediately surrounding the fragments of radioactive material such as dust particles which have been absorbed by the body.

1.4 b Beta particles: β

These particles are about 7000 times lighter than α particles and consequently travel much faster than α particles. Depending on their energy, they can penetrate up to about 5mm in body tissue and the damage they create is spread over a larger region than that created by α-particles.

β particles present an external hazard as well as an internal one, because of their higher penetrating power. However, the β particles produced by the Cs^{137} sources in PMDGs do not penetrate beyond the gauge housings. They are stopped completely by the source encapsulation and surrounding construction materials. In the event of a severe accident exposing the source material, β particles will travel up to 4.5 meters in air, and will be completely stopped, with the emission of a few secondary X-rays.

1.4 c Gamma γ and X-rays

These are both electromagnetic waves of very high to high energy, have no electrical charge and are extremely penetrating in matter. This makes them very useful in applications such as density gauging and level gauging on thick-walled pipes and bins in industrial processes. They behave as though their energy was concentrated in lumps or particles known as photons. At the higher photon energies of Cs^{137} sources, γ radiation can penetrate several centimetres of lead and pass right through the body, including the bone tissue.

(Gamma) γ rays and X-rays differ from charged particles such as α particles and β particles in their interaction with matter. Whereas charged particles will all eventually be stopped if the material is thicker than their range, some γ & X-ray photons are unaffected by absorption processes and penetrate the material. γ rays and X-rays therefore present mainly an external hazard.

For any material, it is possible to define a layer thickness which will reduce the amount or intensity of γ & X-radiation passing through it by one half. This thickness is known as the half-value layer and for Cs^{137} γ -rays in a tungsten shield, it is about 4 mm. The tungsten shields on PMDG source holders are typically 12 to 20mm thick, and cause a reduction in radiation levels by a factor of between 8 and 32. (For PMDGs, the shielding is better in the direction of the user's body. because of the longer path through the shield. It is extremely important that these shields remain intact according to the manufacturer's design, which is approved for use in each State of Australia by the State Health Department. (Devices must satisfy stringent examination of their design at a State level, to confirm that the individual State Standards and national Codes of Practice are met.)

Neutrons

Neutrons have no electrical charge or other electrical properties. This makes them extremely penetrating because they are totally unaffected by the electrically charged electron clouds in the matter they pass through. They can however collide with nuclei, which then recoil, producing **very dense ionization** in the surrounding material. The process of slowing fast neutrons down is called **moderation**. This is more likely to occur by collisions with the nuclei of lighter elements; in fact, one of the best moderators of fast neutrons in the hydrogen nucleus. (The collisions are "elastic", just like billiard balls. Common sense tells us that billiard balls are best slowed down by successive collisions with a series of other billiard balls, rather than by hitting larger objects such as bowling balls.) Once the neutrons have been slowed to **"thermal" velocities**, they can be absorbed by the target helium-3 nuclei in the moisture detector of the PMDG. Neutrons present both an internal and an external hazard. Collisions to thermalisation for different materials are shown in Table 3, which shows why neutrons are extensively used to measure the moisture (In the form of hydrogen, present as H_20) content of a wide variety of materials.

Table 3 also shows that boron is effective in absorbing slow neutrons. It is often chosen on a cost basis for this purpose, mixed with a moderator such as wax, or high-density plastics, especially polyethylene.

CHAPTER 2: RADIATION PROTECTION

Introduction

Radioisotopes are inherently dangerous substances, and the general aim of legislation is to **"protect persons and the environment from health risks associated with exposure to sources of ionising radiation"**. The Australian Federal Government controls the entry into Australia of radioisotopes. The Australian Customs and Border Protection Service is advised by ARPANSA of radioisotopes intended for industrial use. State Governments regulate the use of radioisotopes in order to protect workers and the public from possible radiation hazards. In Queensland, the owner of a radioisotope has to obtain a license to **possess** it, and is required to exercise special care and discretion to ensure that the inherent danger does not become a real one. All radioactive devices have to be approved in Queensland before purchase under this License. In the Queensland State legislation (Queensland Radiation Safety Act 1999) every individual PMDG user must obtain a **License to Use.** (This includes transport of PMDGs only) This makes the Queensland regulations closer to those in other Australian States. Applicants must have both appropriate training and relevant experience - similar to obtaining a Driver's Licence.[1]

A single exposure to an intense Ionising radiation field is capable of causing radiation sickness and death in extremes. Prolonged exposures in lower intensity fields carry the possibility of cancer and of birth defects. However, provided you adhere to the **Safe Working Rules** and **Emergency Procedures** developed by your Radiation Safety Officer (RSO) as part of the approved **Radiation Safety & Protection Plan (RSPP)**, you will Minimise your exposure to, and dose of, radiation. The very low levels of Ionising radiation that you are exposed to at work should not affect your health - but to be convinced of this, you need to understand the concept of **dose,** and **dose limits** in relation to background radiation levels and higher, more dangerous radiation levels.

Dose limits for exposure to radiation have been recommended by the International Commission for Radiological Protection (Publication 103 – 2007) and earlier. The earlier limits are consistent with current occupational health and safety standards and have been adopted in Australia in the RPS C-1 Code for Radiation Protection in Planned Exposure Situations and RPS G-2 Guide for Radiation Protection in Existing Exposure Situations. These are free to download from the ARPANSA website.

In many instances it is possible to use 'rules of thumb' to estimate the dose rate that would be received at a particular point due to a radioactive source of known type and activity. By using appropriate shielding around radioactive sources, and by limiting the time that you are close to the sources, your exposure can be Minimised and kept well below the dose limit. In all cases, doses should be kept **ALARA - "As Low As Reasonably Achievable".**

You need to know the control measures that can be taken to Minimise the hazards associated with radiation and radioactive material. When **CARE is** applied, no harm need come to any person working with Ionising radiation.

Radiation Units and Dose Levels

When material is irradiated by Ionising radiation, it absorbs energy. The unit of **absorbed radiation dose**, the **Gray**, is defined in terms of the radiant energy absorbed per kilogram mass. The **effective radiation** dose, which allows for the type of radiation and part of the body irradiated is the **Sievert**.

Dose limits for Ionising radiation have been internationally agreed, and are given as the dose in **Sievert**, which is accumulated over a given time period. The limits distinguish between people who receive exposure due to their employment and all others in the general population who do not expect to receive an occupational exposure. These dose limits are 20 mSv to the whole body per year for radiation workers and 1 mSv per year for General Public. Once a female radiation worker declares her pregnancy, her radiation work must be modified to ensure the total effective dose to the developing foetus doesn't exceed 1 mSv. Higher limits apply to particular parts of the body, for example the extremities (hands & legs) have a dose limit of 500 mSv - this is because there are no rapidly dividing cells in the extremities.[3] Compliance with these is part of **the approved Radiation Safety & Protection Plan**, incumbent on the owner and users of the PMDG.)

Notes:

1. Apply for radiation licences and approvals | Queensland Health for advice to users, application forms etc.
2. In a single year, a radiation worker may have a total dose of 50 mSv as long as the rolling 5 year average does not exceed 100 mSv.

Background Radiation Levels

To put these dose limits into context, we need to discuss background radiation levels. It is little appreciated that we are continually being subjected to natural forms of Ionising radiation from a variety of causes, which are collectively called **background radiation**, and which must be corrected for in dose rate measurements. We are bombarded by radiation from the Sun and outer space called **cosmic rays**. The Earth contains **natural radioactive materials**, which are a significant source of internal heat, generated as radioactive decay proceeds. These radioactive materials thus **occur naturally** in soil, rocks, water, and air, and also find their way into food and building materials. There is some variation in the level of background radiation when different places are compared, due to the underlying causes differing from place to place. The largest causes of the whole-body background dose are:

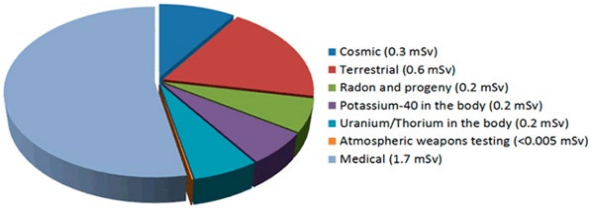


Figure 5: Average annual radiation exposure in

Each of these causes varies; in consequence background ranges from 1 to 2 mSv/year around the world, but some places are known to have considerably higher background levels. For example, some granites contain large amounts of K-40 as potassium feldspar, and higher levels of minerals like monazite, which contain thorium; consequently, background levels are elevated. Castle Hill in Townsville, for example, has a background of up to 4 mSv/year, while parts of Cornwall, England have even higher dose rates. When these granites weather and mineral sands form from them, so these areas can also have higher levels. Considerable areas of Kerala State in India, for example, have a background level of up to 13 mSv/year. It is important to note that these areas do not report significantly higher levels of genetic abnormalities or cancer. [1]

In other areas, uranium and its daughter radium may be higher than average. Again, higher background levels in such areas does not seem to cause health problems, although care must be taken that accumulations of the **gas radon** don't occur, for example in the basements of buildings in cold climates with central heating. The gasses radon and thoron are significant contributors to the dose to the lungs. As these gasses are **a-emitters**, the background dose to the lungs can typically be some 1 mSv higher than the whole-body dose.

From consideration of background radiation levels, it should be apparent that the General Public dose limit of 1 mSv/year above background to the whole body, is a conservative dose limit. Since natural background levels are considerably higher in some places with no apparent ill effects to native populations, the 1 mSv/year limit is a suitably low and simple reference level for external sources of X- and y-radiation.

Note [1] At the time of this revision, the highest background dose to areas of human habitation is up to 260 mSv per year at Ramsar in northern Iran, where some 2,000 persons are exposed. Ramsar and Radioactivity.

Damaging levels of Radiation

In terms of the dose units defined above, 1 Sv, or **1000 mSv**, is a moderate dose level for a single whole-body dose which will cause symptoms of **radiation sickness** to appear in most Individuals. These tissue reaction symptoms are related to damage to rapidly dividing cells in the digestive system and are typically nausea and diarrhea. Fatigue may also occur due to damage to red blood cells, while damage to the white cells and platelets can causes immune deficiency, and internal bleeding. The severity of these symptoms increases with the dose level, until at doses of 5 to 8 Sv, all exposed individuals will die of radiation sickness in the following four weeks, even with specialized treatment. (If the dose is localized to a particular area of the body, only that area will be damaged. This is the basis for the treatment of inoperable cancers, such as brain tumours, or in post-operative treatment of malignant cancers.)

Low doses of less than 100 mSv do not cause immediate harm, but there are some cumulative effects that are of concern if such doses are repeated. Unlike radiation sickness, however, these effects are "random" in the sense that some individuals will exhibit a serious side effect such as genetic damage or cancer, while others exposed to similar doses will not. This is because the crucial damage occurs to the genetic material, or the DNA. In a **single** human cell, it is then a matter of chance whether this cell proliferates, and the damage is expressed in tangible ways. Or the cell may die or be attacked successfully by a healthy immune system. Despite the random nature of the causes of chronic, **low-level doses** of radiation, realistic estimates can be made of the effects. For cancer of all types, the risk of a fatal cancer being induced by cumulative doses of Ionising radiation totalling 1000 mSv is considered to be 4.5%. At the radiation worker limit of 20 mSv, the risk is considered to be proportionally less, and becomes just under 0.1% that a fatal cancer was caused by a radiation dose. Expressed another way, this is around 1 in 1,000, and is obviously "small but finite". This is a good reason for the radiation dose limits to be treated as absolutes (in radiation protection terms, this equates to the **ALARA Principle**: all doses should be kept "As Low As Reasonably Achievable".

At the **1 mSv general public dose limit**, the risk extrapolates to 0.005%, or about 1 in 20,000, if the **"Linear No Threshold"** model is used. It is good common sense that doses at background should not be a cause of cancer. After all, humans are the most successful mammals, and if our DNA were susceptible to damage from background levels of Ionising radiation, "we" would not be here today. It has been suggested that this is simply because DNA that was susceptible to radiation damage at background levels has not survived for long enough to successfully reproduce.

Genetic damage is another possible outcome of radiation damage to cellular DNA in the human reproductive cells. These cells are by their nature particularly sensitive to radiation damage at the time of conception, and in the first few months of the foetus' life. The observed "normal" spontaneous rate of birth defects of all types in humans is ~0.8%, and it is estimated that this rate might be doubled by a radiation dose of about 500 mSv to one of the parents. (This "doubling dose" comes from experiments on mice and animals with similar DNA to humans, however it has not been able to be confirmed in humans.) Extrapolating to a 20 mSv dose, and expressing the result as an **INCREASE in this risk**, a radiation worker may face an increased risk of 1 in 25 or a birth defect. To put this as plainly as possible, the risk might increase from **0.8% of a natural birth defect, to 0.83% of natural + radiation-induced birth defect**, following an exposure to a single dose of 20 mSv. Of considerable concern is that genetic damage is essentially permanent, and that the genetic damage may not be expressed until later generations. (The United Nations expresses this as a risk of 0.3% per Sv of "severe genetic harm" in the first generation, and 1.2% per Sv for all generations. These are "worst case" figures - there is no firm evidence for viable human mutations, but the UN is understandingly being conservative.)

To put the estimation of risks of low doses into some perspective, the following statement from the US Health Physics Society should be borne in mind, as it contradicts the risk estimates made using the **"Linear No Threshold"** model as described above.

"*Radiogenic Health Effects Have Not Been Observed Below 100 mSv":*

Radiogenic health effects (primarily cancer) are observed in humans only at doses in excess of 100 mSv delivered at high dose rates. Below this dose, estimation of adverse health effects is speculative. Risk estimates that are used to predict health effects in exposed individuals or populations are based on epidemiological studies of well-defined populations (e.g. the Japanese survivors of the atomic bombings in 1945 and medical patients.) exposed to relatively high doses delivered at high dose rates. Epidemiological studies have not demonstrated adverse health effects in individuals exposed to small doses (less than 100 mSv) delivered in a period of many years."

Contamination with Radioactive Materials:

There is a common misconception that external radiation sources such as X- and γ-rays cause internal contamination within the body. This is simply not the case, as contamination cannot occur from the use of sealed sources in industrial gauges. The radiation emitting from such sources passes through the body, leaving behind ionization damage, but not radioactive "contamination", which would add to the naturally occurring materials already in the body. Contamination with radioactive materials can and does occur from reactor accidents like Chernobyl and Fukushima, and from the past atmospheric testing of nuclear weapons. In these circumstances, radioactive materials in the form of dust, particles and gasses can spread widely as contaminants through the atmosphere, through the hydrosphere, or into the soil.

Dose Limits in context of background radiation:

Now that the dose limits have been explained in relation to the background radiation level of 1 mSv/year, and the dangerous levels of above 1000 mSv, it is instructive to also consider operational levels around radiation gauges. The **ARPANSA Code of Practice and Safety Guide for Portable Density/Moisture Gauges Containing Radioactive Sources (RPS 5 - 2004)** fixes the dose limit at 1 meter from the surface of a gauge in the shielded storage/transport container at **10 µSv.h^{-1}** (or 0.01 mSv.h^{-1}). You would therefore have to work at this distance from the gauge for 100 hours to obtain a dose equivalent to the annual background dose, and for 2000 hours to obtain the dose limit of 20 mSv for a radiation worker. It is apparent that care should be exercised in these circumstances, although most PMDGs have dose rates of 2 -3 µSv.h^{-1}, well within this limit. An important part of your Safe Working Rules is to wear a badge sensitive to neutron and gamma radiation while using the PMDG, as this is the best way to monitor your accumulated dose. If you are concerned about the radiation levels near the PMDG in your work area, ask the RSO to demonstrate with a survey meter what these levels are. (Remember that for a normal gamma survey meter like the Rotem Ram Gam 1 or Automess, this only shows half of the total dose received from the Am^{241}/Be source, as explained below. It will, however, be accurate for the dose from the Cs^{137} source, provided the meter has been **calibrated,** and also passes a **consistency check**. Calibration is required annually, while the consistency check is required when critical measurements such as surveys of your source containers are performed. Survey meters such as the Rotems are calibrated in units of µSv.h^{-1}, so to obtain your accumulated dose, you will need to multiply by the number of hours you have been exposed to obtain µSv.

In discussions on received dose such as in the paragraph above, the **ALARA principle** should always be kept in mind. This states that all doses should be kept As Low As Reasonably Achievable, and it is very important in radiation safety practice.

CHAPTER 3: RULES OF THUMB FOR EXTERNAL DOSE CALCULATIONS

Point Sources

A "point" source is defined as one whose physical size is small compared with the range of the emitted radiation in the substance being considered, and with the distance between source and detector. The sources used in PMDGs can be considered as point sources, as the actual source pellet is less than about 5 mm in diameter. This enables us to use some simple formulae to estimate the Dose rate at a Distance (or DRAAD). We have purposely used the source activity specified by the gauge manufacturer. For Troxler, Humboldt and Campbell-Pacific gauges.

Point source Cs^{137} gamma emitter

Cs^{137} gamma source: With the source activity expressed in Becquerel's, the DRAAD equation is:

Cs^{137} Dose rate at distance of 1 meter:

Dose Rate @ 1m = 104 x G ($\mu Sv.h^{-1}$)

where 104 is the specific gamma ray factor for Cs^{137} and G is activity in GBq

Using the value of 300 MBq Cs^{137} source in the Troxler 3440 PMDG, if this source is exposed but not ruptured, the gamma dose at one meter (d = 1m), will be:

R = 104 x 0.300 µSv/hr

= 31.2 µSv/hr at 1metre

Based on the ICRP standard of 2000 hrs per work year, this would be 1.24 mSv per week. The annual 20mSv limit for radiation workers would be exceeded after 16 weeks. If the distance from the source is increased to 2m, the weekly dose would fall to around 0.31 mSv per week.

This is not considered a particularly dangerous dose rate if the exposure is intermittent, although it is 160 times typical background. It is the dose rate only when the density probe is extended for measurement. With the probe inserted into soil, there is a shielding effect which increases with the depth of the probe. The use of tungsten as a shield in the body of the PMDG reduces this dose rate further when the probe is retracted. Note that while this dose rate is low, that at the surface of the extended probe is quite high - we estimate around **900 mSv/hr at the probe surface** some 5 mm from the source. This should especially be borne in mind while using, cleaning and maintaining the PMDG. Another factor to consider in an extremely severe accident, or vandalism, is **source rupture**. This may involve much higher doses within 1 meter of the source due to β radiation. Because of this, and the risk of contamination, Users are advised as part of the Emergency Procedures to contact the RSO immediately and arrange for appropriate assistance.

Ruptured Cs^{137} source

Dose rate within 4.5 meters very high due to β radiation.

(Note that at 4.5 meters, the β rays are completely absorbed by air, although some secondary X-rays could be present. **Any boundaries set for emergencies should be at a minimum of 5 metres for a Cs^{137} source**.)

The annual limit of 20 mSv could be received in about 9 hours, at 1 meter from the exposed ruptured source, so this is obviously a serious dose. It should be stressed that a dose of this size is only possible if the source is ruptured and source material is completely exposed; this would require a major accident from the construction of the density probe. Unfortunately, the use of PMDG in road construction has resulted in severe accidents to PMDGs on at least an annual basis in Queensland, although there has not yet been notification of a ruptured source. It can't be over-emphasized that under the Queensland regulations, the **PMDG User is responsible for preventing severe damage to the gauge**. This is primarily why users are required to be individually licensed. Should such an accident occur, it is essential that the User be able to recognize such damage & call an experienced Radiation Safety Officer or Technologist to deal with it.

Point Am^{241}/Be neutron source

This compares closely with the value of 24 $\mu Sv.h^{-1}$ calculated from the 1.48 GBq source activity Am-241/ Be neutron source.

With the source activity expressed in Becquerels, the DRAAD equation is:

Am^{241}/Be, Dose rate at distance of 1 meter

Dose Rate @ 1m = 1.3 x G ($\mu Sv.h^{-1}$)

where 1.3 is the specific gamma ray factor for Am^{241} and G is activity in GBq

so at 1 meter:

R = 1.3 x 1.48 µSv/hr for the 1.48 GBq Am/Be source.

= 1.92 $\mu Sv.h^{-1}$ at 1 meter (composed of 1.0 $\mu Sv.h^{-1}$ from neutrons with another 1.0 $\mu Sv.h^{-1}$ from gammas, (shielded within the source capsule for PMDG use). This is clearly less by a factor of 20 than the DRAAD for the Cs^{137}source, and so you should not be unduly concerned about this source. However, it must be noted that, unlike the Cs^{137} source, this source has no extra shielding when the PMDG is made Safe. Some relatively minor shielding from neutrons is provided by the transport case, so from a safety viewpoint, the PMDG is not completely Safe, even when it is in the transport case. The

PMDG should always be returned to the transport case when not in use - to protect the gauge from damage, and to protect you.

For CPN PMDGs, the sources are 300MBq Cs^{137},and 1850MBq Am^{241}/Be, so the dose rate at 1 meter

The combined gamma dose from the exposed Cs^{137} and Am^{241}/Be sources at 1 meter is therefore 24 uSv.h^{-1} for Troxler PMDGs, so this is what is measured by a survey meter.

The neutron dose is a negligible (in these circumstances) additional 1 uSv.h^{-1}.

will be proportionally higher, at 30 µSv.h^{-1} gamma, and 1.3 µSv.h^{-1} neutron.

Humboldt PMDGs uses sources of 300MBq Cs^{137}, and 1480MBq Am^{241}/Be, so the dose rate at 1 meter will be 30 µSv.h^{-1} gamma, and 1 µSv.h^{-1} neutron.

CHAPTER 4: SAFETY MEASURES WITH IONISING RADIATION AND RADIOACTIVE MATERIALS

The safety measures employed when using Ionising radiation and radioactive materials, are based on no harm coming to persons exposed, provided that:

- exposure to Ionising radiation is kept below the dose limits set by the Regulator in each state, and
- no radioactive materials are allowed to enter the body.

A number of control measures are therefore necessary to achieve these objectives. Whenever any project makes significant use of Ionising radiation or radioactive materials a competent person is appointed with a responsibility for all radiological safety aspects of the work. This person is known as the Radiation Safety Officer (RSO).

The RSO's job is to ensure that the administration of the project is thorough, that people working on it know about the hazards and how to overcome them, and that the radiation levels are regularly monitored. It is very important that doses are also Minimised to project workers who don't use these devices, and to the "general public". In this regard, security of the devices must be maintained at all times, whether in use, transport or storage.

The RSO should also ensure that the three main technical measures to Minimise radiation exposure are taken. These measures are:-

Time of Exposure

This involves ensuring that personnel are exposed to Ionising radiation for the minimum possible period during the course of their work.

In utilizing time as a protective measure, it may be necessary to set a working time for persons in a high radiation field to prevent overexposure. The time limit can be calculated simply as:

t = D/d hours where D is the dose limit (mSv)

d is the dose rate in the area (mSv/hour)

e.g. for an exposure limit of 20 mSv over a working year of 50 weeks, this is 0.4 mSv/week. If the dose rate is 0.026 $mSv.h^{-1}$, (or 26 $\mu Sv.h^{-1}$, at 1 meter) the working time limit is 0.4/0.026 = 15.4 hours.

This is a useful calculation for the RSO, as it defines the maximum dose rate, beyond which the annual dose limit may be exceeded. In the case of PMDGs, you can't work a 40 hour week at 1 meter from the exposed source, but obviously that is not how the gauge is meant to be used. As well as the Safe Working Procedures, distance from the PMDG is also very important.

Distance

This is made use of by ensuring that personnel remain at the largest possible distance from sources of Ionising radiation. For a point source the inverse square law applies. Put simply, this law says that the dose of radiation from a radioactive source decrease with the square of the distance between the source and the person receiving the radiation. For example, if the distance is doubled the radiation dose received will be one-quarter. Similarly at three times the original distance only one ninth of the radiation dose will be received. Its important to consider that if the distance is halved, the dose rate will be quadrupled.

The effect of distance is illustrated by the graphs in Appendix 5, where dose rates for both Cs^{137}, and Am^{241}/Be sources have been plotted against distance for common PMDG source activities. The same scales have been used to enable comparison of the doses from each source type.

It is easy to see why 5 meters is recommended as a safe distance from a damaged PMDG in an emergency, as the dose rate will then be 1 $uSv.h^{-1}$ or less, even in the worst case of a ruptured Cs^{137} source. This dose rate is only some 7 times typical background levels.

Shielding

This involves the use of adequate amounts of shielding materials whenever persons are working in the vicinity of sources of penetrating Ionising radiation. Provision for proper shielding permits individuals to work much closer to a source of Ionising radiation, and for longer periods, than if no shielding is provided. For gamma radiation large thickness of heavy material (e.g. lead, iron, tungsten etc) are required. The concept of half value layer (HVL) for is a unit measurement of material that will attenuate radiation levels by 50%. For example, tungsten is the material of choice for the shield plate, which slides across to shield the Cs^{137} source when it is made Safe (Beam OFF position), while tungsten is also the material used in the cylindrical shield into which it is withdrawn. Concrete blocks or even bagged soil or gravel are effective shields on work sites.

As a practical example of the use of shielding, consider cleaning the source rod on a soil density gauge. This can be done safely by consciously placing the trunk of your body in the "shadow" cast by the source shining on the shield block, particularly if the rod is not fully extended - deliberately place yourself in this position. There is no protection for hands, arms and the head, but you will be minimizing your dose to the more sensitive parts - the trunk of the body.

For neutron sources, shielding is a three-part process:

1. The fast neutrons must first be moderated. For transport containers. This is usually achieved by the use of either paraffin wax, which is not inflammable, or a dense polyethylene. In permanent stores, cement blocks or even shallow boreholes are used.

2 . The moderated neutrons must then be absorbed. This is generally achieved by the addition of boron, in the form of borax (sodium borate) to cements or the wax. However, care must

be exercised that the boron is well distributed into the moderator, or "beams" of thermal neutrons may escape the shield. A cadmium sheet is sometimes used as an efficient neutron absorber.

3. Finally, some moderation and capture reactions generate high energy gamma photons, typically 2 MeV, so the shielding must be sufficiently thick to attenuate these. A capture reaction is involved in the He^3 nuclei in the Troxler neutron detector. These produce protons in the reaction, which, being charged particles, are readily detected in the ionization chamber of the detector. The helium nuclei are present as a gas under pressure.

4.4 Summary: How can YOU minimise your dose?

By applying the following factors:

Time: **- eg: Take good measurements first time round**

Distance: **- eg: Take one step back during measurement (at least)**

Shielding: **- eg: Place soil samples between PMDG & vehicle occupants**

CHAPTER 5: WORKING RULES FOR USE OF PMDGs

Only an outline sufficient for PMDG use is presented here. Full details on approvals and appropriate signage, etc are held by the RSO.

Working Rules for Soil Density & Moisture Measurement

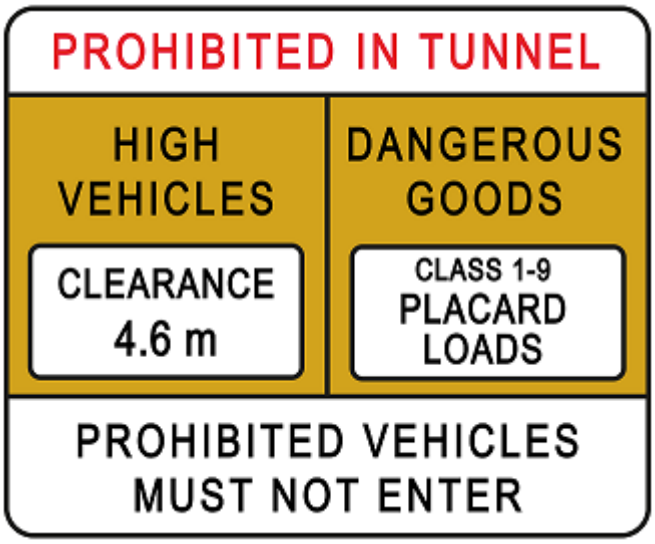
- Area warning signs are to be displayed in the vicinity of the PMDG during use. The use of the transport vehicle should be considered both as warning and protection for the PMDG in appropriate situations.
- Persons not required for the measurements must be excluded from the vicinity.
  The source rod must only be protruded from the body of the gauge immediately prior to making a measurement.
- When making a measurement, take at least one step back from the PMDG This reduces the user's dose dramatically. (ALARA principle.)
- The PMDG must be locked in SAFE (Beam OFF) and replaced in the transport container immediately on completion of the measurements.
- The PMDG mustn't be left unattended unless securely stored in a transport vehicle or field store.

Personal Monitoring

- Badges (personal dosimeters) must be worn at chest or waist height at all times during transport of, and using, PMDGs.
- When not being worn, they are to be placed away from the gauge and direct sunlight etc (on a designated peg-board or similar.)
- Gamma dosemeters are acceptable, but it is clearly preferable to use a dosemeter that will record both neutron and gamma doses, so that the wearer's total dose is monitored.
- The Control badge is never to be worn as a substitute for personal dosimetry
- ***NEVER LEAVE YOUR BADGE IN THE TRANSPORT CASE WITH THE PMDG !***

Transport

- Only licensed drivers who are authorised by the Possession Licensee can transport PMDGs.
- PMDGs shall only be transported in their transport containers. (These are approved Type A containers, in accordance with the **ARPANSA RPS C-2 (Rev. 1) Code of Practice for the Safe Transport of Radioactive Material-2019**.)
- PMDGs must be transported with the source **locked** in the SAFE (Beam OFF) position. The survey meter is used to ensure the beam is properly attenuated.
- It is important that the transport case be secured in the rear of the vehicle such to deter dislodgement in the event of a vehicle roll over or collision.
- If a survey meter is not available, the User must verify by inspection that the shutter is closed during transport. Shutter blocks can hang open as the return spring weakens with usage.
- PMDGs must not be transported in the passenger compartment of the vehicle. They must be placed at the maximum distance from the driver's position and suitably restrained in place.
- Transport signs are to be fixed to both sides and rear of the vehicle, only when the PMDG is being transported.
- For transport by consignment with an external transport company (who must be licensed in Queensland), please see the advice in the Troxler Safety Training Program, particularly if consigning by air, and/or to an overseas destination.
- You must ALWAYS obey Local Traffic Rules



http://www.tmr.qld.gov.au/safety/driver-guide/tunnel-safety.aspx

Storage

- When not in use, PMDGs are to be stored in approved facilities.
- Only the Licensee & RSO have keys to the Store.
- PMDGs must be stored in transport cases, locked in the **SAFE position**. The survey meter must be used to check the gauges are **SAFE**.
- PMDGs must be signed in and out of the Store, with the name of user and location details. It may be convenient to record standard counts and User safety inspections on the same sheet
- Wear your badge whenever in the Store.
- **Field storage** is using the transport vehicle to store an PMDG when it can't be returned to the approved Radiation Store. It must be marked in the Store log as such. Then take all precautions: lock the transport case inside the vehicle & place the 3 transport placards over the case (so they are obvious if someone breaks into the vehicle, but not from outside.) Immobilize the vehicle. If staying in a Motel, discuss with the Manager where Dangerous Goods vehicles are to be parked. (Ionising Radiation is **Class 7 Dangerous Goods**)

Repairs & Maintenance

- Only repairs and maintenance intended by the manufacturer to be done by the user are to be performed on PMDGs. This includes cleaning of the retraction mechanism, as described in the particular handbook. Failure to clean this moving part can result in buildup of fine material, eventually jamming the slide open. This results in the PMDG having a beam of gamma radiation emerging from the lower surface.

- The return spring that drives the shutter block closed must be inspected when cleaning the shutter, and replaced at regular intervals. Every 2 years usually matches the gauge calibration interval.

- All other maintenance and repair work is to be conducted by a licensed Radiation Technologist

CHAPTER 6: EMERGENCY PROCEDURES

What is an emergency?

An emergency is any incident or accident resulting in a loss of control of the radiation sources. The following situations are considered to require implementation of the emergency procedures, in approximate order of increasing severity:

- Source rod won't retract.
- Accident to gauge transport vehicle.
- Suspected or observed damage to the PMDG.
- Loss of source/gauge.
- Impact, fire, flood or other disaster.
- Theft or vandalism.

While it isn't possible to give hard and fast rules to cover every conceivable emergency, the following should be used as **guidelines.**

Please note that, as an absolute priority, anyone injured must receive appropriate first aid. The design of PMDGs is sufficiently robust as to ensure contaminating accidents are only remotely possible, under the most extreme circumstances - and have not occurred in Australia to date. The dose rates from the sealed sources used in these gauges are sufficiently low (as described above in Chapter 3), that first aid can't be denied on this ground. As a licensed User, you must be able to reassure Emergency Services personnel on this important point.

Emergency Procedure if PMDG obviously damaged

- Park safely and barricade off area and restrict access within ~5 meters of the damaged gauge. Contact police if a traffic hazard could arise in the event the gauge cannot be moved out of traffic flow.
- Stay close enough to the damaged PMDG to control access to the accident site
- Contact the RSO
- Don't attempt to move the PMDG unless directed to do so by your RSO.
- If necessary, provide shielding & security for the damaged gauge by carefully covering the gauge with about 0.5 m3 of sand or gravel etc (bagged, bearing in mind you'll eventually have to recover the damaged gauge). Place traffic warning signs & construction barriers around the site.

- However, this method isn't acceptable in built-up areas, or where vehicles have access. In this case, half fill a 200-litre drum with sand, gravel or crusher dust. Seal the damaged PMDG in a stout plastic bag, and then place the PMDG in the drum after advice from the RSO. Then completely fill the drum, and transport it to a secure area, where it can be stored awaiting further action. Bagged shielding material would be preferable for easy recovery of the PMDG.

- Note it is the RSO's responsibility to notify the Possession Licensee of the incident.

Emergency Procedure if PMDG not obviously damaged

- The first four steps are as above.

- The RSO will survey the gauge with the meter.

- If the results agree with previous surveys, and the source is in the shielded position, the gauge should be returned to the Store, but not used until checked and recertified by a Radiation Technologist.

- If the results are significantly different, the gauge is damaged, and should be treated as such.

Incident Reporting

An incident report is to be submitted to Radiation Health (at the address below) by the Licensee within seven (7) days of the incident. The report will include:

- a description of the Incident

- estimates of radiation exposure to individuals

- action taken

- changes to the Radiation Safety Plan to prevent a recurrence.

Radiation Health:	**Radiation Safety Adviser**
Phone:	**07- 3328-9310**
Facsimile:	**07-3328-9622**
Mobile:	**0413-279-672 (emergencies & out of hours)**
Address :	**Radiation Health, Butterfield St, Herston Q 4006.**
Website:	**http://www.health.qld.gov.au/radiationhealth/**

Appendix 1 Emergency Contacts

Emergency Contacts (This list to be displayed prominently and kept up-to-date.)

Licensee:	Your Company's Licensee:
Phone:	Mobile and office numbers:
	After hours:
Radiation Safety Officer:	Your Company's RSO:
Phone:	Mobile and office numbers:
	After hours:
3rd contact:	**EXAMPLE**
	Mr. Joe Bloggs
Main Roads Calibration Laboratory	XXXXXXXXX
Laboratory Phone	XXXXXXXXX
Emergency Service Provider:	000 or Brisbane Police Communications Centre
Phone:	07 3328 9310 mention it is a **radiation related incident** to ensure appropriate response - very important!

Appendix 2 Wipe Testing

The aim of wipe testing is to test a surface for the presence of removeable contamination. This is usually the closest accessible point to the source, or in a severe incident it may be the source capsule itself. Always assume the wipe will remove radioactive materials that you can be exposed to, so you will need to take reasonable precautions when taking and analysing a wipe test. As a minimum, this means avoiding contact with your bare hands – always wear disposable gloves. If the wipe result is positive, the gloves will also be contaminated.

There are several suppliers of wipe test kits, including MES. Detailed instructions are provided. These are used when the wipe is taken at the intervals specified in the Safety Plan, as a condition of the Company Possession Licence.

Here is a default procedure for when you do not have such a kit:

Wipe Test Procedure for an Incident:

1. Obtain **white cotton cloth** ideally, or paper towel.
2. Decide whether a dry wipe or **a wet wipe** is advisable.
3. A wet wipe using **distilled water** or a solvent such as **isopropyl alcohol** is preferred, unless the fluid may further cause damage. This doesn't apply to the sturdy source capsules used in PMDGs.
4. **Mark an ID (Gauge Serial No.) & date** for the wipe on about 100mm square of your material & use tongs or tape to a wooden rod to form a swab.
5. Use pencil preferably, as solvents will smear the ID.
6. **Put on gloves**.
7. **Wipe** the affected area with the marked side of the swab – wipe inwards & clean the surface as much as possible.
8. **Place the wipe** & then your gloves in a **sealable plastic bag** marked with full wipe ID & contact details.
9. **Test the exterior of the bag** with a survey meter. If contamination has been removed, you still may not get a reading above normal background on a standard (gamma only) survey meter.
10. If you have a **contamination meter, test** the wipe before step 6 to see if the contamination has been removed.
11. Take or send the **wipe for analysis**. You may need advice on how to do this. As a guide, if the surface dose rate on the sealed bag is **< 5 µSv.h^{-1} gamma**, it can be posted or couriered without external radiation markings as an Excepted Package.

Appendix 3 Information from Troxler on Source Construction and Half Life:

Radioactive materials are continually decaying, so their activity decreases with time as the amount of material decreases. The time taken for a given amount of radioisotope to decay to one-half of its original activity is known as half-life: the half-life of Cs^{137}, for instance, is 30 years.

The following Table illustrates the decay of an 296MBq Cs^{137} source after various periods of time:

Time (in years)	Activity
(date of measurement)	296 MBq
1	289.34
5	263.81
10	234.95

The radioactive materials used in Troxler gauges are all classified as special form, encapsulated sealed sources.

Typically, the gamma source, Cs^{137} is first fused with a ceramic to form a small bead. This bead is then fusion welded inside a stainless-steel capsule, which is in turn welded inside the stainless-steel source rod.

The Am^{241}/Be mixture of the neutron source is first compressed into a pellet and then fusion welded into two consecutive stainless-steel housings.

The only health concerns to Troxler gauge users are the actual emissions necessary for moisture and density measurement. There is no likelihood of any gauge user coming into contact with any radioactive material under normal conditions.

Also, the source encapsulation and shielding stop any alpha and beta particles that are produced by the source.

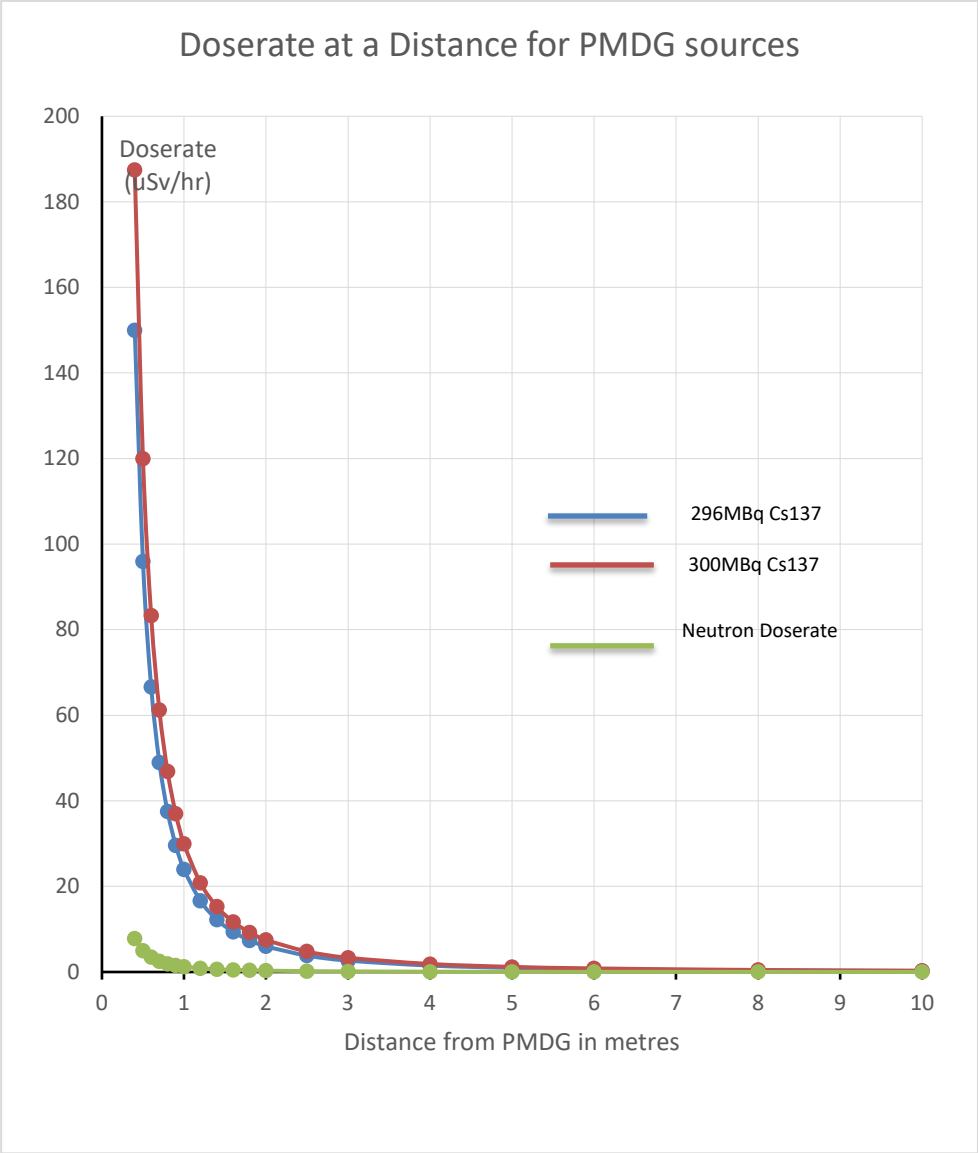
Appendix 4 Radiation Measurement

Human beings have no senses capable of detecting nuclear radiation. Therefore, instruments must be used both to warn of the presence of the radiation, and to measure its strength. In Troxler gauges, the detectors of interest are Geiger-Mueller (G-M) tubes for gamma radiation and helium-3 (He^3) tubes for neutrons.

The most common type of radiation detector is the G-M tube. The typical G-M tube consists of a gas-filled metal cylinder with a wire running down the centre. The special gas filling enables a single Ionising event in the gas to produce and avalanche of electrons, resulting in an easily detectable electric pulse. The G-M tube therefore counts radioactive emissions passing through the detector.

Neutrons, being uncharged particles, do not directly produce ionization. Just as neutrons are produced by a nuclear reaction, they must also be detected by a nuclear reaction. When a thermal neutron strikes a helium-3 nucleus, a proton is ejected, and the product nucleus is hydrogen-3. The proton, being positively charged, can be detected. A neutron detector is a metal cylinder with a central wire, similar to the G-M tube, and a filling of high-pressure helium-3 gas.

Appendix 5 DRAAD for Portable Density and Moisture Gauges



Notes:

1. Dose rate is a strong function of distance from the source – even the neutron source. Care must be taken if cleaning inside the gauge to keep your hands there only for the minimum time possible.
2. Similarly, if cleaning the source rod, Minimise the time the source is exposed.
3. 5 metres is a safe distance from a damaged PMDG
4. The dose rate shown for the Am^{241}/Be source is that for neutrons alone – the gammas are shielded by tungsten inside the source capsule.

Appendix 6 Extract from RPS C-1

RPS C-1 Code for Radiation Protection in Planned Exposure Situations (Rev.1) (2020)

Schedule A Dose limits for occupationally exposed persons

Type of limit	Limit (18 years and over)[1]	Limit (more than 16 years but under 18 years)[1,5]
Effective dose	20 mSv per year, averaged over a period of five consecutive years[2]	6 mSv per year
Annual **equivalent dose** to the lens of the eye	20 mSv per year, averaged over a period of five consecutive years[3]	20 mSv per year
Annual **equivalent dose** to the skin[4]	500 mSv per year	150 mSv per year
Annual **equivalent dose** to the hands and feet	500 mSv per year	150 mSv per year

[1] The limits apply to the sum of the relevant doses from external exposure in the specified period and the 50-year committed dose from intakes in the same period.

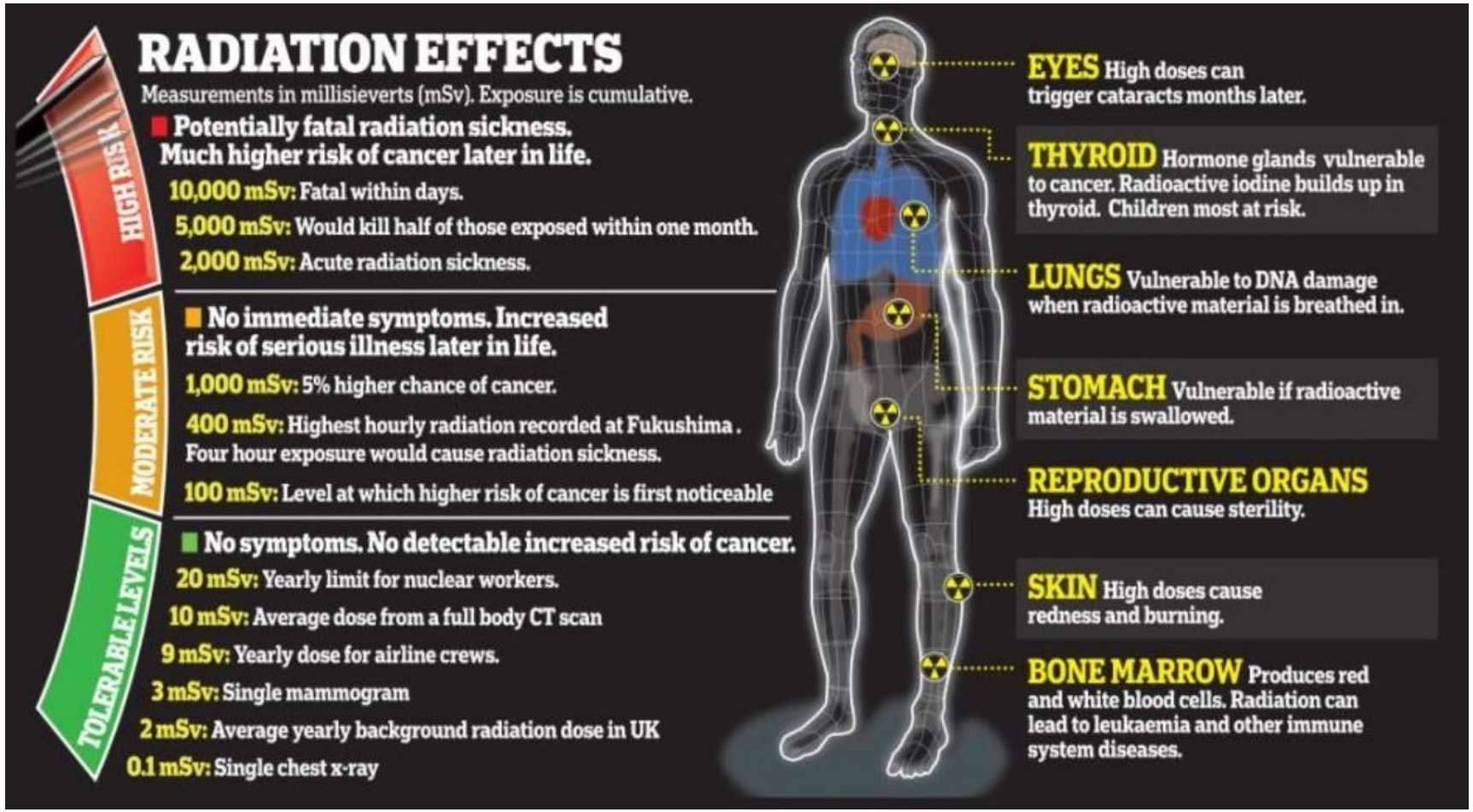
[2] With the further provision that the effective dose must not exceed 50 mSv in any single year. When a pregnancy is declared by an occupationally exposed female, the working conditions of that person should be such as to ensure that the additional dose to the embryo/foetus would not exceed about 1 mSv during the remainder of the pregnancy.

[3] With the further provision that the equivalent dose must not exceed 50 mSv in any single year.

[4] The equivalent dose limit for the skin applies to the dose averaged over 1 cm^2 of the most highly irradiated area of the skin. The dose to the skin also contributes to the effective dose, this contribution being the average dose to the entire skin multiplied by the tissue weighting factor for the skin.

[5] Persons under the age of 16 years must not be subject to occupational exposure. Persons under the age of 18 but more than 16 years must not be subject to occupational exposure unless they are under supervision and only for the purpose of training for employment or for the purpose of studies in which sources are used

Appendix 7 Effects from Short Term High Radiation Levels



Appendix 8 Queensland Penalty Units

Notes on Penalties and Penalty Units

There are penalties that apply for breaches of the ***Radiation Safety Act 1999.***

Penalties are stipulated in terms of a number of penalty units that range from 10 to 2500. Each penalty unit carries a certain dollar value that is calculated by reference to the ***Qld Penalties and Sentences Act 1992.*** The dollar value of a penalty unit increases each year.

As of 1 July 2024, the value of a penalty unit is $161.30

Example of the penalties and they apply:

13. Requirement for use licence

(1) A person must not use a radiation source, unless the person is allowed to use it under a use licence.

Maximum penalty—

(a) for a radiation source that is not a portable security enhanced source—400 penalty units; or

(b) for a portable security enhanced source—2500 penalty units.

Example of when a person needs a use licence—

Under section 49(2), only an individual may apply for a use licence.

(2) Subsection (1) does not apply to a person if—

(a) the person is using the source in the presence, and under the personal supervision, of a use licensee who is allowed, under the licence, to use the source to carry outa radiation practice; and

(b) the use is for the purpose of

(i) helping the licensee to carry out the practice, if the practice is a prescribed radiation practice; or

(ii) the person undergoing training prescribed under a Regulation

Example: You have not completed your supervised logged hours on the PMDG and DO NOT have a licence to "USE" the PMDG. This means that any work you do with the gauge must be supervised by a licenced User.

If you use the gauge without the appropriate supervision (ie: unattended) without a licence, you can face a maximum penalty of 400 x $161.30 = $64,520

Table 1. Periodic Table of the Elements

showing for each: element name, atomic number, chemical symbol, and atomic weight

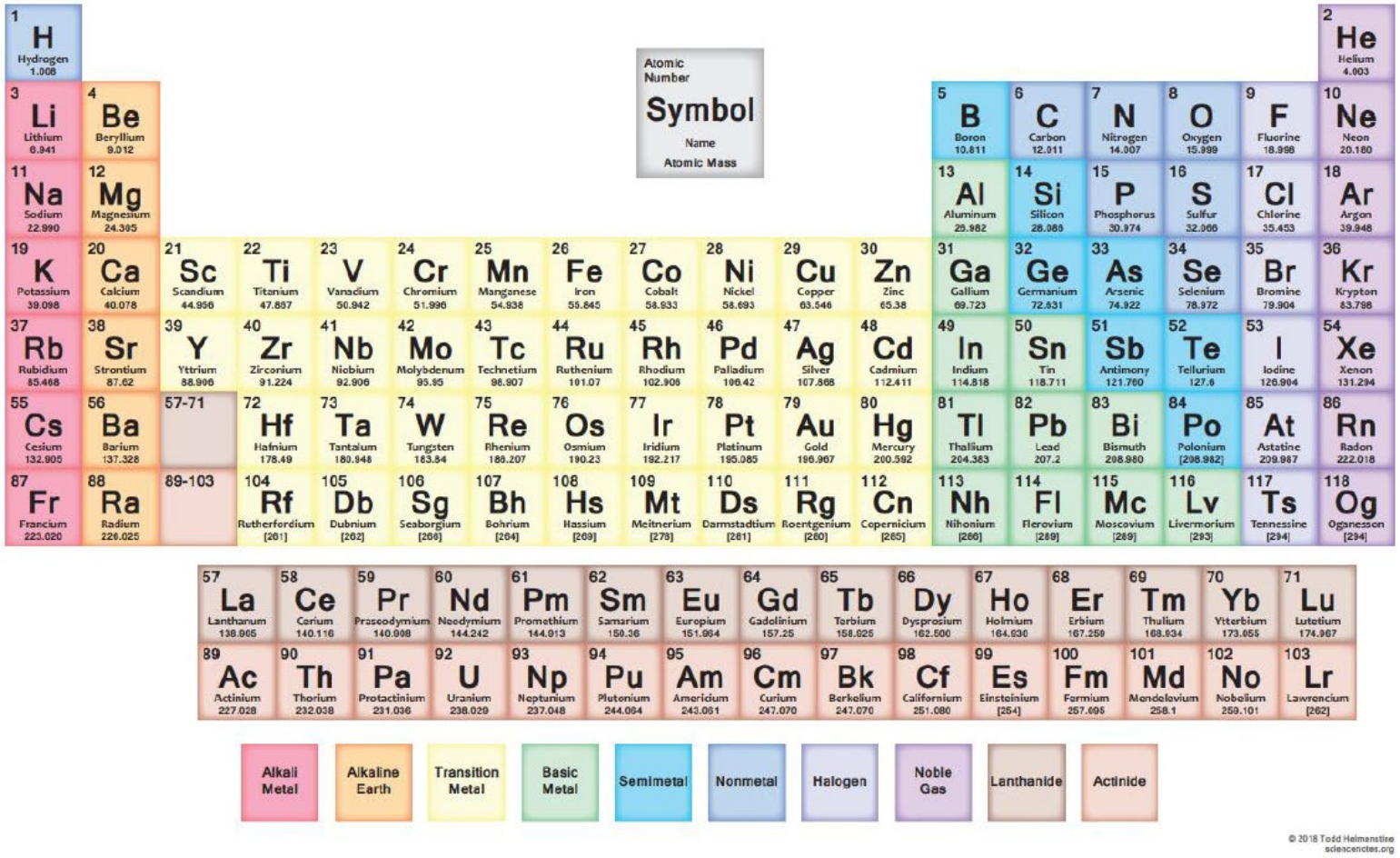


Table 2. Table of the Isotopes

(from the CRC Handbook of Physics and Chemistry, 67th Edition)

Isotope	Half-life	Decay mode	Energy (MeV)	Gamma Energy (MeV)	Intensity	Comments
n	12 min	β-	0.783	NA		Free neutron decay
H-3	12.26 yr	β-	0.0186	NA		Tritium decay
C-14	5730 yr	β-	0.157	NA		
Na-22	2.605 yr	B+ (90%)	2.84	0.511 (annihilation)	180%	Calibration γ spectrometers
		E.C (10%)		1.274	100%	
P-32	14.28 d	β-	1.71	NA		
K-40	1.25 x 10e9 yr	β- (89%)	1.32	NA		
		B+ (10.7%)	1.5	0.511 (annihilation)	200%	Background radiation
		E.C. Electron capture		1.46	100%	
C0-60	5.272 yr	β-	0.315	1.173	100%	Industrial radiography
				1.332	100%	
Ni-63	100 yr	β-	0.065	NA		Source in Ion spectrometry
Se-75	118.5 d	E.C.	0.864	Many; peak at 0.265	~150%	Industrial radiography
Kr-85	10.72 yr	β-	0.687	0.514	0.43%	
Sr-90	29.12 yr	β-	0.546 + Y-90	NA		Paper thickness gauging
Y-90	64.0 hr	β-	2.283	NA		Paper thickness gauging
I-131	8.04 d	β-	0.606 (89%)	0.364	81%	Fission product (in fallout)
			0.334 (7%)	0.637	7%	
				0.284	6%	
Ba-133	10.53 yr	E.C.	52%	Cs Ka X-ray	63%	Industrial gauging eg ashmeter
Cs-137	30.17 yr	β-	1.17 + Ba-137m	0.661	85.10%	Industrial gauging
			0.512 (95%)			
Ba-137m	2.552 min	Internal Trans	0.661	0.661	90%	
		β-	0.624, 0.656	Ba X-rays		
Ir-192	73.83 d	β-	1.454	0.316	83%	Industrial radiography
				0.468	48%	
				0.308	30%	
				0.296	29%	
				0.604	8%	
Po-210	138.4 d	α	5.407 + progeny	0.803	0.0011%	Static eliminators
Ra-226	1600 yr	α	4.87 + progeny	0.186	3.3%	Part of U-235 decay scheme
Rn-222	3.82 d	α	5.59 + progeny	0.51	0.07%	Part of U-235 decay scheme
Pu-238	87.74 yr	α	5.593	0.02 (U K X-ray)	5.2%	XRF gauging
U-234	2.45 x 10e5	α	4.856	0.053	0.12%	
Am-241	432.2 yr	α	5.637 + Np-237	59.5 keV	35.7%	Smoke detectors, XRF
				0.02 (NpL X-ray)	20%	Neutron source (as Am/Be)
Np-237	2.14 x 10e6 yr	α	4.957	0.02 (Pa L X-ray)	25%	
Cf-252	2.64 yr	α (96.9%)	6.217	0.02 (Cm L X-ray)	2.9%	Elemental analysis gauging
Spon. Fission (3.1%): Used as source of fast neutrons				From the CRC Handbook of Physics and Chemistry, 67th Ed.		
See also; Decay schemes for Natural Isotopes: U-238, U235, Th-232 for background radiation						

Table 3. Collisions to Thermalisation and other data for neutrons

(reproduced with permission from Troxler Safety Notes for Soil Density and Moisture Gauge)

ELEMENT	WEIGHT FRACTIONS OF EARTH'S CRUST	COLLISIONS TO THERMALISATION	THERMAL ABSORPTION CROSS SECTION
Hydrogen	0.0041	19.0	0.33
Boron	*	109.2	759.00
Carbon	*	120.6	0.0034
Nitrogen	*	139.5	1.90
Oxygen	1.466	158.5	0.002
Sodium	0.028	224.9	0.53
Magnesium	0.021	237.4	0.063
Aluminium	0.081	262.8	0.23
Silicon	0.277	273.3	0.16
Phosphorous	0.001	300.8	0.19
Sulphur	*	311.1	0.51
Chlorine	*	343.3	33.00
Potassium	0.026	378.0	2.1
Calcium	0.036	387.3	0.43
Titanium	0.004	461.6	6.10
Manganese	0.001	528.5	13.30
Iron	0.050	537.2	2.53
Cadmium	*	1074.6	2390.00
Lead	*	1975.5	0.17
Uranium	*	2268.6	4.20

Neutron Thermalisation and Absorption Data

* **Weight fraction is less than 0.1%**

Table 4. Radiation Profile for Troxler 3430

TABLE 1.0 RADIATION PROFILE FOR TROXLER MODEL 3430 GAUGE

	SURFACE			10 CENTIMETRES			30 CENTIMETRES			1 METRE		
	GAMMA	NEUTRON	TOTAL	GAMMA	NEUTRON	TOTAL	GAMMA	NEUTRON	TOTAL	GAMMA	NEUTRON	TOTAL
GAUGE												
Front	130	17	147	50	17	67	11	3	14	3	1	4
Back	260	14	274	80	14	94	25	5	30	4	1	5
Left Side	130	5	135	40	5	45	7	2.5	9.5	1	1	2
Right Side	120	7	127	80	7	87	25	2.5	27.5	4	1	5
Top	190	17	207	80	17	97	6	7	13	1.5	1	2.5
Bottom	180	60	240	25	60	85	6	9	15	1	1	2
TRANSPORT CASE WITH GAUGE												
Front	100	7	107	50	7	57	12	4.5	16.5	2.5	1	3.5
Back	70	8	78	30	8	38	8	2.5	10.5	1	1	2
Left Side	3	1	4	2.5	1	3.5	1	1	2	1	1	2
Right Side	50	30	80	20	30	50	6	7.5	13.5	2	1	3
Top	100	4	104	25	4	29	6	3	9	1	1	2
Bottom	100	7	107	50	7	57	20	2	22	3	1	4

* From Model 3430 Manual - Troxler
* measurements converted from mrem to uSv
* For nominal source activities of Cs-137 296MBq & Am241/Be 1.48GBq

Table 5. Radiation Profile for Troxler 4640

TABLE 2.0 RADIATION PROFILE FOR TROXLER MODEL 4640-B THIN LIFT ASPHALT GAUGE

	SURFACE	10 CENTIMETRES	30 CENTIMETRES	1 METRE
	GAMMA	GAMMA	GAMMA	GAMMA
GAUGE				
TOP	25	11	3.5	1
BOTTOM	30	12	4	1
LEFT	30	15	4	1
RIGHT	50	36	14	2.5
FRONT	200	70	8	1
BACK	70	10	3	1
TRANSPORT CASE WITH GAUGE				
TOP	25	9	3	1
BOTTOM	10	5	2.5	1
LEFT	30	16	7	2
RIGHT	35	15	4	1
FRONT	15	6	3	1
BACK	70	7	4	1

* From Model 4640-B Manual - Troxler
* measurements converted from mrem to uSv
* For nominal source activitY of Cs-137 300MBq
* Source rod locked in off position

TABLE 6: Relationships Between S.I. Units and Non-S.I. Units

Descriptor	Non S.I. UNIT	S.I. UNIT	Relationship
Activity	Curie (Ci)	Becquerel (Bq) 1 Bq = 1 disintegration/sec	1Bq = 27pCi 1 Ci = 37 GBq
Absorbed dose	Rad	Gray (Gy) 1 Gy = 1 J/kg	1Gy = 100 rads 1 rad = 10 mGy
Equivalent	Rem	Sievert (Sv)	1Sv = 100 rems 1rem=10mSv
Exposure	Roentgen (R)	Coulomb/kilogram (C/kg)	1C/kg = 3.87 kR R = 258 uC/kg

References:

- *Radiation Safety Act 1999*
- *Radiation Safety Regulation 2021*
- *Standard for radiation sources–industrial, mining, manufacturing, and other practices (2021) Section F*
- *RPS C-1 Code for Radiation Protection in Planned Exposure Situations (Rev.1) (2020)*
- *RPS 5 – ARPANSA Code of Practice and Safety Guide* Portable Density/Moisture Gauges Containing Radioactive Sources (2004)
- *RPS 2 – ARPANSA Code of Practice for the Safe Transport of Radioactive Material (2008)*
- *RPS 1 - Recommendations for Limiting Exposure to Ionizing Radiation (1995) and National Standard for Limiting Occupational Exposure to Ionizing Radiation (republished 2002)*
- *RPS No. 6 - National Directory for Radiation Protection (including amendments 1-6) - February 2014*
- *http://large.stanford.edu/courses/2018/ph241/lance2/*

Document Control

Revision History

REV	DATE	COMMENT	AUTHOR	APPROVED
1.0	22/10/1997	Establishment of Document	B. McKavanagh	B. McKavanagh
1.1	05/03/2024	Annual Review, Formatting	P. Allanson	K. Lawrenson
2.0	14/01/2025	Annual Review, QMS Formatting	P. Thompson	K. Lawrenson