Radiation Safety Training for Transport of Class 7 Goods

Radiation Transport Level 2 Course

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These notes have been developed for "persons seeking to obtain An individual Transport Licence—transport radioactive substances by road." (Applies to public roads as defined by the Land Act 1994)

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Acknowledgments:
Adapted from MES (McKavanagh Engineering Services Pty Ltd) RSO Level 1 Notes
ARPANSA Code for the Safe Transport of Radioactive Material Radiation Protection: Series C-2 (Rev. 1) March 2019
IAEA Regulation for the Safe Transport of Radioactive Material: Specific Safety Requirements No. SSR-6 (Rev. 1) 2018

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Figure 1: Health Physics posters used at Oak Ridge National Laboratoy in 1947 – still relevent today! (courtesy of Oak Ridge Associated Universities).

1. INTRODUCTION

These course notes have been prepared specifically for use by persons wishing to obtain a Transport Licence—transport radioactive substances by road under the Queensland Radiation Safety Act 1999 (the Act), and Radiation Safety Regulation 2021 (the Regulation), in Queensland. This training course has been provided to the administrating authority in Queensland, Radiation Health.

RADIATION HEALTH CONTACT DETAILS

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The primary aim of transport of Class 7 Radioactive Substances is that under all foreseeable circumstances, radiation exposure to individuals is minimised and kept below acceptable limits. Your Radiation Protection Program outlines responsibilities of both the Company and Individual involved with transport of Class 7 consignments.

A fundamental requirement is that the person responsible for transport shall obtain, and maintain, knowledge of:

- the principles and practice of radiation protection,
- potential hazards associated with transporting radioactive substances,
- radiation monitoring and measurement practices, and
- means of protecting employees and the environment from radiation.

2. RADIATION SOURCES

Before we start on radiation safety and Transport of Class 7 Dangerous Goods, it is worthwhile spending some time looking at just what a 'radiation source' is. The Radiation Safety Act 1999 defines radiation as "Either ionising or non-ionising radiation" and a radiation source means "a radioactive substance or a radiation apparatus". The difference between a radioactive substance and a radiation apparatus is that the apparatus when de-energised, does not emit radiation. Industrial sources are "special form" sources that are designed to be in use for many years and undergo rigorous testing prior to being approved for use.

The difference between industrial radiation sources and those used in the health care industry can be summed up simply, health related applications relate to the exposure of humans to radiation sources (known as radiopharmaceuticals) while industrial radiation sources are usually applied to inanimate materials and products. These radioactive sources are usually in the form of a liquid suspension.

We are continuously exposed to background radiation from within our bodies (Potassium and Thorium), externally from cosmic radiation (the sun and space) and terrestrial radiation (Radon) Medical procedures account for a high statistical portion of background radiation exposure.

2.1 Types of Radiation Sources

A Radioisotope is specifically manufactured or obtained for the purpose of using the emitted ionising radiation. Common Radioisotopes are natural or manufactured radioactive materials or by products of the nuclear fuel process (Uranium isotopes, Thorium isotopes, Cesium 137, Americium 241, Iridium-192, Selenium-75, Technetium-99m, Iodine-131, Radium-223)

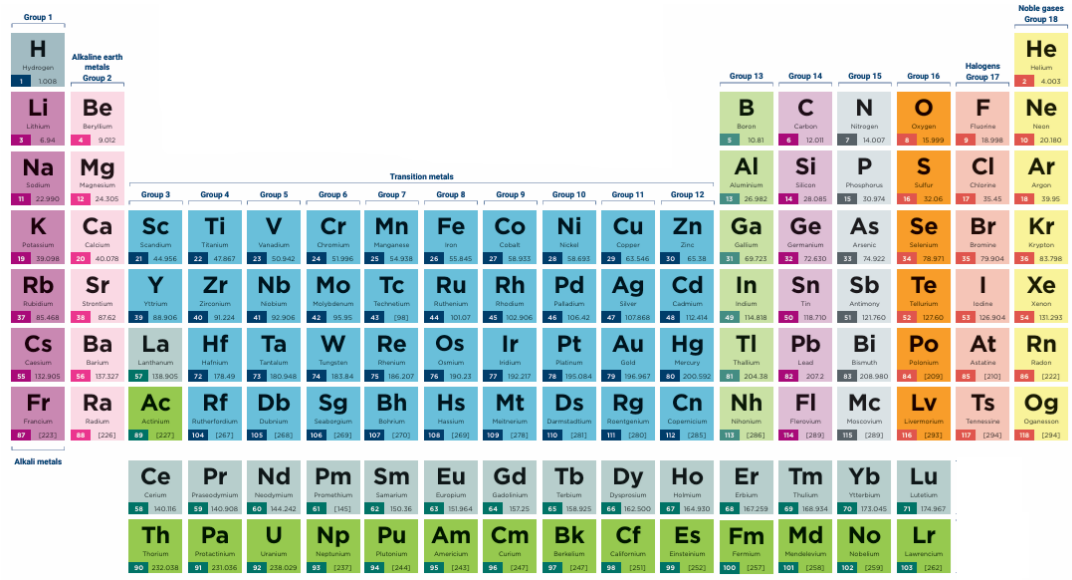


Figure 1: The Periodic Table (Royal Society of Chemistry)

3. RADIATION SCIENCE (PHYSICS)

The emission, or production of radiation, is all about physics, and therefore some time must be spent addressing the fundamental physics behind it all

The electromagnetic radiation spectrum is broad (Figure 2), ranging from low frequency, long wavelengths through to our area of interest, the extremely high frequency, short wavelength gamma rays – the world of ionising radiation.

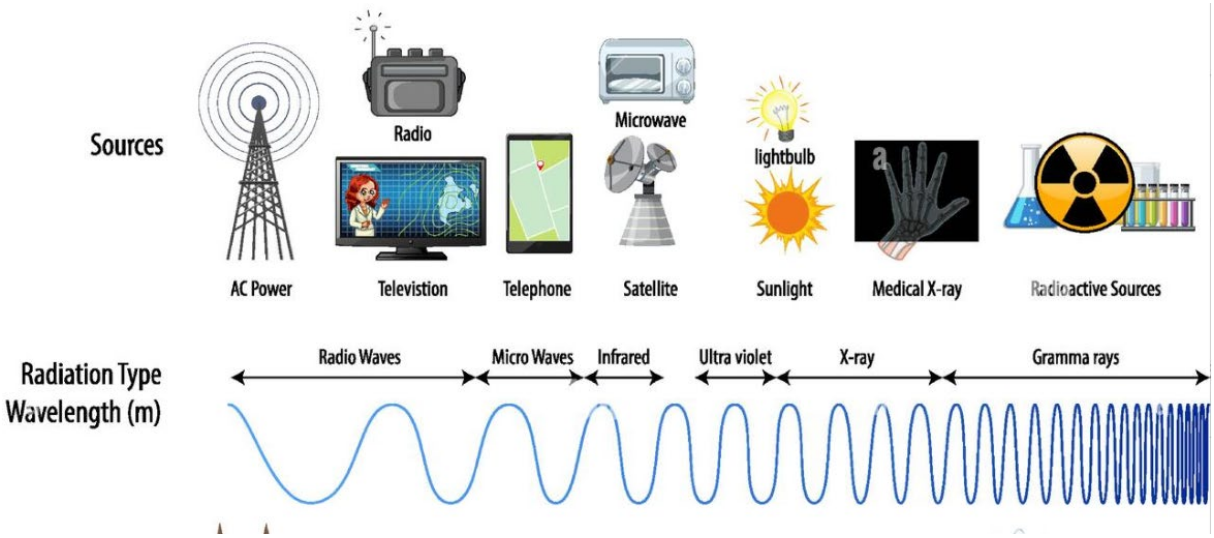


Figure 2: The electromagnetic spectrum (Alamy Images)

3.1 The Basics

Different **isotopes** of the same element have the same number of protons in their atomic nuclei but differing numbers of neutrons, commonly known as Radioisotopes. The term isotope is formed from the Greek roots isos ("equal") and topos ("place"), meaning "the same place".

Radioisotopes are **radioactive isotopes** of an element. They can also be defined as atoms that contain an unstable combination of neutrons and protons, or excess energy in their nucleus.

3.1.1 How do radioisotopes occur?

The unstable nucleus of a radioisotope can occur naturally, or because of artificially altering the atom. In some cases, a nuclear reactor is used to produce radioisotopes, in others, a cyclotron. Nuclear reactors are best-suited to producing neutron-rich radioisotopes, such as molybdenum-99, while cyclotrons are best-suited to producing proton-rich radioisotopes, such as fluorine-18.

The best-known example of a naturally occurring radioisotope is **uranium**. All but 0.7 per cent of naturally occurring uranium is uranium-238; the rest is the less stable, or more radioactive, uranium-235, which has three fewer neutrons in its nucleus.

3.1.2 Radioactive decay

Atoms with an unstable nucleus regain stability by shedding excess particles and energy in the form of radiation. The process of shedding the radiation is called **radioactive decay**. The radioactive decay process for each radioisotope is unique and is measured with a time period called a **half-life**. One half-life is the time it takes for half of the unstable atoms to undergo radioactive decay.

There are approximately 1400 unstable nuclides and isotopes that will undergo decay until a stable nuclide is reached. The lighter nuclei have close to equal numbers of protons and neutrons making them stable. For heavier nuclei there is a significant increase in the number of neutrons to protons. This excess number of neutrons is required to hold the large nuclei together.

The nuclei that lie a great distance from the line of stability are **unstable** and may undergo spontaneous transformations that alter the neutron / proton ratio continually until the resulting nuclei approach the line of stability. As the nucleus changes, the element changes and a radioactive decay series is produced. The original nucleus is called the parent and the decay products called progeny (previously daughters). The change in neutron / proton ratio causes the release of energy, mostly carried away from the nucleus in the form of fast particles and photons.

3.2 Half- Life (or Half Time)

The decay constant is the probability that an atom will undergo decay in unit time. It has a characteristic value for each radionuclide and is related to the half-life. The half-life, $t_{1/2}$, is the time in which the original or parent radionuclide is reduced by a factor of two and is given by:

A simplified formula for calculating new activity of a radioisotope is shown in figure 3.

Simplified: $A=A_o/2^n$

Where: A_o = Original Activity

A = Activity after time T

n = number of half-lives (elapsed time/half-life) $T/T^{½}$

Figure 3: Calculating activity when half-life, original activity and original date is known.

The radioactive decay process is largely insensitive to external conditions and therefore, for a given nuclide, a fixed decay probability (although being statistically derived) and decay mode (Alpha/Beta) can be assigned.

The decay process is important to understand for the preparation of shipping Class 7 goods as the current activity is required as opposed to the original activity. Common isotope half-lives are listed in Table 1.

Radioisotope	Half life $t_{1/2}$	Radioisotope	Half life $t_{1/2}$
Cf252 (Californium 252)	2.67 years	Se^{75} (Selenium 75)	119.8 days
Cs^{137} (Cesium 137)	30.17 years	Ir^{192} (Iridium 192)	73.83 days
Co^{60} (Cobalt 60)	78 hours	*M^{99} (Molybdenum 99)*	66 hours
Ga^{67} (Gallium 67)	5.272 years	*Tc^{99m} (Technetium 99)*	6 hours
Pu^{238} (Plutonium 238)	87.7 years	Am^{241} (Americium 241)	432 years
Po^{210} (Polonium 210)	138.3 days	*I^{131} (Iodine 131)*	8.06 days

Table 1: Example of half-life periods for more common industrial and pharmaceutical radioisotopes.

3.3 Decay Processes

The principal modes of radioactive decay are alpha decay, beta decay, electron capture and gamma emission (Figure 4). Other modes include internal conversion and spontaneous fission.

3.3.1 Alpha decay

- The emission of alpha particles which consist of helium nuclei.

3.3.2 Beta decay

- The emission of either electrons or positrons

3.3.3 Internal conversion

- Internal conversion processes compete with gamma emission processes by surplus energy being transferred to an atomic electron causing it to be ejected from the atom.

3.3.4 Electron capture

- The nucleus captures one of its own electrons, resulting in a proton being converted to a neutron and emits gamma radiation or a gamma-ray and neutrino.

3.3.5 Gamma emission

- Short wavelength electromagnetic radiation in the form of gamma rays is emitted in the transition between two energy levels of the same nucleus.

3.3.6 Spontaneous fission

- Spontaneous fission decay occurs in nuclides with atomic masses above 230. The nucleus dissociates into two near equal parts or fission fragments. Large quantities of energy are released during this process (~200 MeV per fission). The decay process includes the emission

of neutrons and electromagnetic radiation. Neutron radiation can be very penetrating in matter.

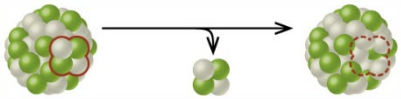
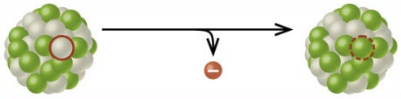
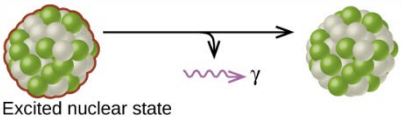
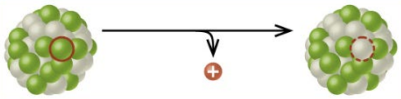
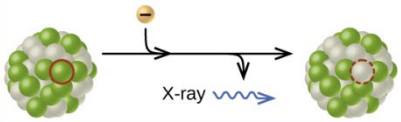
Type	Nuclear equation	Representation	Change in mass/atomic numbers
Alpha decay	${}^{A}_{Z}X \rightarrow {}^{4}_{2}He + {}^{A-4}_{Z-2}Y$		A: decrease by 4 Z: decrease by 2
Beta decay	${}^{A}_{Z}X \rightarrow {}^{0}_{-1}e + {}^{A}_{Z+1}Y$		A: unchanged Z: increase by 1
Gamma decay	${}^{A}_{Z}X \rightarrow {}^{0}_{0}\gamma + {}^{A}_{Z}Y$		A: unchanged Z: unchanged
Positron emission	${}^{A}_{Z}X \rightarrow {}^{0}_{+1}e + {}^{A}_{Y-1}Y$		A: unchanged Z: decrease by 1
Electron capture	${}^{A}_{Z}X \rightarrow {}^{0}_{-1}e + {}^{A}_{Y-1}Y$		A: unchanged Z: decrease by 1

Figure 4: Main decay process (Open Stax – Chemistry 2e)

3.4 Units of Measurements

Radiation physics, and radiation protection, have a language of their own. Australia uses the SI system for units. The non-SI, still used in the United States, is the curie (Ci). The curie is based on the nominal activity of 1 gram of Ra^{226}. You may come across non-Si units when dealing with Type B(U) containers as these are generally manufactured in the United States. There are several good on-line calculators and apps that convert between units, and some basic conversion factors are provided in Appendix A.

There are two general concepts relating to radiation, we can measure the *activity* (*radioactivity*) of a radioisotope. The SI unit for radioactivity is the Becquerel (Bq) and is a measure of radiation emissions per second by a radiation source.

The other unit we commonly use relates to *exposure* and is a measure of the effect of radiation on a substance (air, water, tissue etc.). Radiation exposure can be expressed in several ways that relate the level of harm caused by different types of radiation on different media, and also considers the sensitivity to different tissue types or organs in our bodies. Exposure leads to dose. For industrial exposures we always assume a whole-body exposure, and this is measured in $\mu Sv.h^{-1}$

3.5 Shielding

Each radiation emission has several characteristics that dictate how shielding requirements are determined. As a general statement, shielding requirements for α, β, X and γ, and neutrons are like those shown in Figure 5.

3.5.1 Alpha and Beta shielding

As a rule, very little physical shielding is required for α and β radiation however it must be considered that high decay rate, high β energy radiation will result in Bremsstrahlung (photons) if high-Z shielding materials are used.

To effectively shield these β emissions, a low-Z shielding material (such as plastic) should be used in proximity to the actual β source, and then additional high-Z materials (e.g. lead) are used to shield the produced Bremsstrahlung radiation.

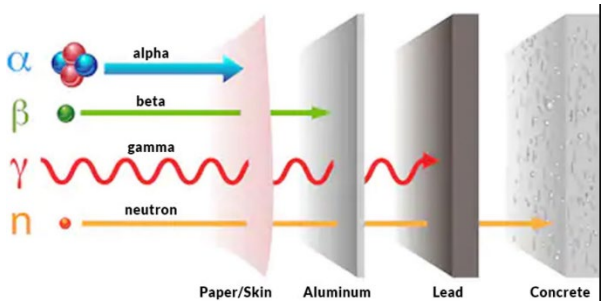


Figure 5: Choosing the correct shielding (MarShield Custom Shielding)

3.5.2 X and Gamma shielding

For any material it is possible to define a characteristic thickness after which half of the photons in the original beam will have been absorbed or scattered. This thickness is known as the half-value thickness (HVL) or half-value layer, because the intensity I of the original beam is reduced by half. Due to the complexity of neutron interactions with matter, Table 2 has HVL thickness for commonly transported radioisotopes.

Radioisotope	Concrete	Steel	Lead
Cs^{137} (Cesium 137)	48mm	16mm	6.5mm
Ir^{192} (Iridium 192)	43mm	13mm	4.8mm
Co60 (Cobalt 60)	62mm	21mm	12mm

Table 2: HVL in common materials for specific radionuclides commonly used in Industry.

3.5.3 Neutron shielding

Shielding of fast neutrons presents a two-stage problem. First, the neutrons must be slowed down or thermalised (the process by which neutrons whose speed by colliding with nuclei in the shield, or target material), then a different material is used to absorb these slow neutrons.

There are several propriety neutrons shielding materials on the market, which have been developed as an effective, fire-resistant neutron shield consisting of a mixture of:

- Water Extended Polymers (developed by Frontier Technology Corporation)
- high-density polyethylene beads
- calcium sulphate hemihydrate (Plaster of Paris), and
- boric acid (in powder form)

These mixtures are mixed like cement and poured directly into place.

Note: These are for neutron absorption and that an outer shield of lead or concrete may have to be added to attenuate the high energy γ rays formed.

Emergency neutron shielding options include a minimum 300 mm cover of sand, gravel, or similar earthen material, preferably moist. Bagged material is preferred to minimise creation of more mobile contaminated material in the event the source encapsulation is breached.

4. BIOLOGICAL EFFECTS OF IONISING RADIATION

The fact that ionizing radiation produces biological damage has been known for many years. The first case of human injury was reported in the literature just a few months following Roentgen's original paper in 1895 announcing the discovery of x-rays. As early as 1902, the first case of x-ray induced cancer was reported in the literature.

Acute effects of high radiation dose exposure can be *burns and necrosis to the skin, radiation sickness, cataracts, hair loss, blood changes, temporary or permanent sterility to death in the extremes.*

Chronic effects from low doses include *cancer and leukemia.*

Genetic effects (passed on to the next generation) *birth defects, still births.*

4.1 Mechanisms of Ionising Radiation Damage

Radiation damage starts at the cellular level. Radiation which is absorbed in a cell has the potential to impact a variety of critical targets in the cell, the most important of which is the DNA. Evidence indicates that damage to the DNA is what causes cell death, mutation, and carcinogenesis. The mechanism by which the damage occurs can happen via one of two scenarios, as shown in Figure 6

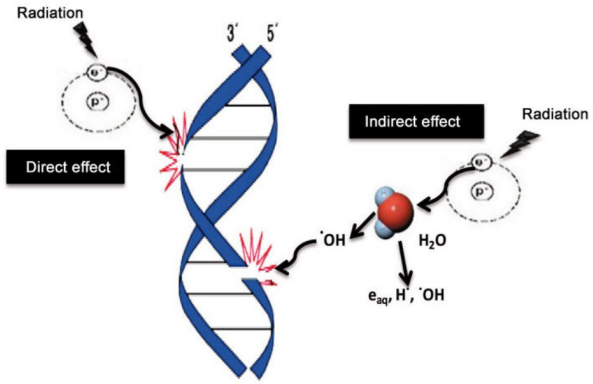


Figure 6: Mechanisms of radiation damage. (ResearchGate)

Most of this damage consists of breaks in only one of the two strands and is easily repaired by the cell, using the opposing strand as a template. If, however, a double-strand break occurs, the cell has much more difficulty repairing the damage and may make mistakes. This can result in mutations, or changes to the DNA code, which can result in consequences such as cancer or cell death. Double-strand breaks occur at a rate of about one double-stand break to 25 single-strand breaks. Thus, most radiation damage to DNA is reparable.

There are four factors that influence the effects of a radiation exposure, the combination of which gives us the total effective dose:

1. The **Rate** at which the radiation is absorbed during a short period as opposed to longer periods where a degree of recovery occurs.
2. The **Larger** the area the greater the overall damage to the organism. Cancer treatment relies on small, targeted exposures rather than whole body exposures.
3. Within the organism affected, there is a variation in the sensitivity of **Cells.** In general, cells that are rapidly dividing are more susceptible to radiation damage.
4. There is a wide variation in the **Radiosensitivity** of various species. Within the same species, there can be a variation between **Individuals** as well.

The lethal dose for each species is expressed in statistical terms, usually for animals as the LD50/30 for that species, or the dose required to kill 50 percent of the individuals in a large population in a thirty-day period. For humans, and acute dose of 3 – 4 Sieverts (Sv) would be a mortality of LD50/30 (the dose required to kill 50 percent of the population in 30 days), assuming no treatment is given. It can be as high as 8 Sv with adequate medical care. (Table 3)

Short term effects of acute radiation exposure

from the US Centre for Disease Controls Emergency Response site:
http://www.bt.cdc.gov/radiation/arsphysicianfactsheet.asn

Dose (Sievert)	Effects (Note: LD 10/30 means 10% mortality in General Public after 30 days)
0.05 - 0.2	None felt; low risk of cancer & genetic damage.
0.20 - 0.50	None felt; red cell count decreases temporarily.
0.50 - 1.00	Mild; headache, increased risk of infection, temporary male sterility (TMS) possible.
1.00 - 2.00	Mild; **LD 10/30**, moderate nausea, vomiting 3 - 24 hrs, then latency in felt effects 10 -14 days, then illness/fatigue, immune system depressed, TMS, stillbirths/ miscarriages.
2.00 - 3.00	Moderate; **LD 35/30**, Nausea, vomiting, hair loss, fatigue, massive loss of white cells, males permanently sterilised & females possible. Convalescence 1 - several months.
3.00 - 4.00	Severe; **LD 50/30**, increased symptoms as above + uncontrollable bleeding in mouth, skin & kidneys.
4.00 - 6.00	Acute; **LD 60/30** (90% at 6 Sv) death primarily from infection I internal bleeding; convalescence several months to a year.
6.00 - 10.00	LD **100/14**; survival only with intense medical care & bone marrow transplant.
10.00 - 50.00	LD **100/7;** intense symptoms within 5 - 30 mins, latent phase up to several days, then certain death due to failure of circulation (water-electrolyte imbalance).
> 50.00	Death < 50 hours.

Table 3 – Short term effects of acute radiation exposure. (US CDC)

5. RADIATION PROTECTION

Radiation protection legislation, regulations and safety standards vary on a State-by-State basis across Australia, and then again when operating within Federal agencies. While legislation does vary, the principles of radiation protection are based on international standards adopted by Australia. The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) has developed, in consultation with State regulatory authorities, a number of documents that outline the recommended radiation protection standards for Australia, and these recommendations are then adopted by the States through local legislation.

The ARPANSA Code of Practice for the Safe Transport of Radioactive Material (RPS Series C-2 Rev.1) Section 302-303 requires a radiation protection plan is established and if the effective dose is:

(a) Is likely to be between 1 and 6 mSv in a year, a dose assessment programme via workplace monitoring or individual monitoring shall be conducted; or

(b) Is likely to exceed 6 mSv in a year, individual monitoring shall be conducted.

5.1 Dose Limits

The occupational and member of the public dose limits for ionising radiation are given in Table 4 and Table 5.

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.

Table 4: Occupation Dose Limits for ionising radiation. (ARPANSA RPS C-1)

Type of limit	Dose Limit[1]
Effective dose	1 mSv per year[2]
Annual **equivalent dose** in the lens of the eye	15 mSv per year
Annual **equivalent dose** in the skin[3]	50 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 (to age 70 years for children) from intakes in the same period.

[2] In special circumstances, a higher value of effective dose could be allowed in a single year, provided that the average over five years does not exceed 1 mSv per year.

[3] The equivalent dose limit for the skin applies to the dose averaged over any 1 cm^2 area of skin, regardless of the total area exposed. 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.

Table 5: Member of Public Dose Limits for ionising radiation. (ARPANSA RPS C-1)

5.2 Practical means of limiting external exposure include:

- Reducing exposure time, directly proportional.
    - The most direct way to reduce radiation dose is to reduce the time spent working with or in the vicinity of radiation sources.
    - If the exposure time is cut in half, the dose will be reduced by the same fraction.
    - (Time spent x dose rate = dose received)

- Increasing the distance from the source
    - Distance is one of the most effective means to reduce dose thanks to basic principles of geometry.
    - When the working distance from a radiation source is increased by a factor of two, the dose received from that source will be reduced by a factor of four.
    - This is referred to as the inverse square law, i.e., the radiation intensity from a source decreases with the square of the distance from the source.

- Use of shielding (see Section 3.5)
    - Shielding is any material used to reduce the intensity of radiation by absorbing or attenuating the radiation coming from the source.
    - Nuclear gauges and projectors have a significant amount of shielding already built in to protect the operator. This is calculated during manufacture and uses a known Half-Value Layer (HVL)factor.
    - The most common shielding material against γ radiation is lead (Pb) while the most effective is depleted uranium (DU)

6. RADIATION DETECTORS & SURVEY METERS

It is well established that ionising radiation cannot be seen, smelt or touched. With this in mind, radiation detectors and instrument must be used to detect the presence of external radiation fields, surface contamination or radioactivity in air, water and solid materials. To complicate the matter

further, one type of radiation detector is not able to measure all the different types of radiation, or radioactivity being investigated.

Most radiation survey meters also need batteries or an AC power supply, so make sure your instruments are always in perfect working order (Figure 7)

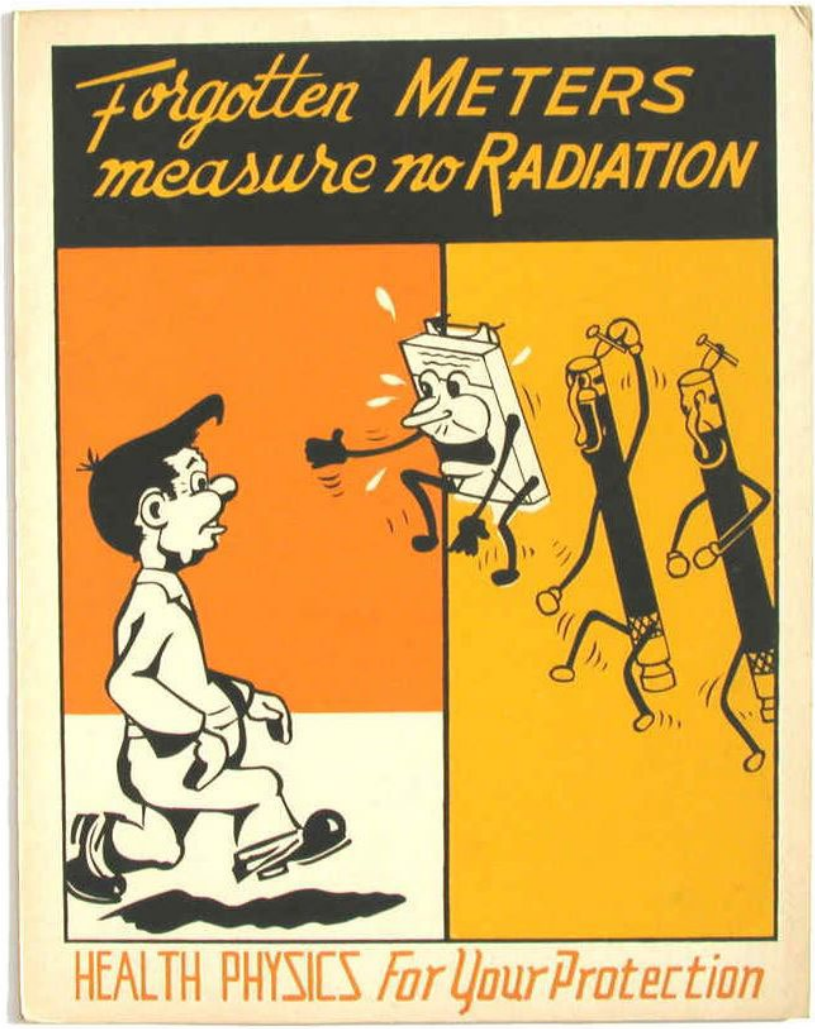


Figure 72: Words of wisdom (courtesy of Oak Ridge Associated Universities).

All methods of detecting ionising radiation rely on energy being deposited in the radiation detector. This deposition of energy generally results in Ionisation of the detector medium, either directly or indirectly. The interactions involved depend on radiation type, energy and detector medium. Most detectors convert the deposited energy into a useable electrical signal. The most common detector uses a Geiger-Muller tube which provides a dose rate in either µSv/hour or mRem/hour. Unfortunately, there isn't one detector to suit all types of radiation, this section will look at the most common.

G-M detectors are commonly used for measurement of beta and gamma radiation; however, they can also detect alpha radiation with low efficiency. Typical G-M detector-based instruments are shown in Figure 8).



Figure 8: A selection of common G-M detector survey meters, from left to right; Tracerco T406 for X-ray and γ, Automess 6150 and QSA RADEYE survey meters using internally mounted G-M detectors (Images: Tracerco, Automess and NDT Equipment Sales)

6.1 Basic Considerations in Selections of a Detector

A detector for a specific application (and we are focusing on portable survey instruments here) must be selected by considering a number of factors:

- efficiency and range / sensitivity;
- requirement (or not) of spectroscopic information;
- energy dependence;
- angular dependence;
- response to unwanted radiations;
- environmental effects such as temperature, pressure, humidity. vibration, electromagnetic fields;
- response time;
- reliability;
- portability, and
- Cost

6.2 Detector checks

Prior to using the detector provided:

- Check the calibration date has not exceeded the (12 Months Calibration period)
- Check the battery is operating and if the level is displayed, that it is suitable for the intended duration.
- Check the unit for any obvious damage.
- If possible, check the response against a known radiation source if safe to do so.

6.3 Personal Monitoring

6.3.1 External Dosimetry

A dosimeter is a small radiation detection device worn by an individual, used to measure doses from ionizing radiation.

Dosimeters may be classified into two general categories, passive and active:

- A passive dosimeter produces a radiation-induced signal, which is stored in the device. The dosimeter is then processed, and the output is analyzed.
- An active dosimeter produces a radiation-induced signal and displays a direct reading of the detected dose or dose rate in real time.
- The recommended placement of a dosimeter is on the trunk of the body, between the waist and neck. This positioning provides a good estimate of effective dose in situations where the body is uniformly exposed to radiation.
- Always defer to your Radiation Safety and Protection Plan or Radiation Management Plan requirements for dosimetry.

6.3.2 Passive dosimeters

Passive dosimeters are provided to users, who wear them for a defined period of time (this time period is called the exchange or wear period). The dosimeters are then returned to a dosimetry service, which processes and analyzes them and sends the dose results to users.

There are many types of dosimeters for measuring beta and photon radiation. These include film dosimeters, thermoluminescent dosimeters (TLDs), optically stimulated luminescence dosimeters (OSLDs), and direct reading dosimeters (DRDs). These examples are shown below.



Figure 9: TLD badges (left), and typical TLD 'chips' in holders (centre) and a OSLD (Images: ARPANSA)

6.3.3 Active Dosimetry

Direct Reading, Personal Electronic or Personal Alarm Dosimeters are active dosimeters since they display doses and dose rates while they are being used. Many direct reading dosimeters have alarms that sound at preset doses and dose rates. Figure 10 displays a common DRD / PED device.



Figure 10: Typical example of a DRD / PED (Image: QSA Global)

7. CLASS 7 TRANSPORT

The Queensland Radiation Safety Act 1999 requires that when radioactive substances are transported, the consignors and carriers concerned must comply with the Code of Practice for the Safe Transport of Radioactive Material (RPS C-2) as amended from time to time, published by ARPANSA.

The main object of the Act is to protect persons and the environment from the harmful effects of particular sources of ionising radiation and harmful non-ionising radiation.

We have covered the basic principles of radiation physics, the effects of radiation exposure and how to minimise the radiation dose. These basic principles must be understood to ensure that the transport of radioactive substances is carried out safely and in accordance with code of practice.

7.1 Dangerous Goods Class

There are restrictions on what classes can be shipped with radioactive substances. Figure 11 provides a ready reference on segregation of dangerous goods.

May be loaded into the same vehicle or freight container unless a numbered exception applies — Refer to exception (1) — May **not** be loaded into the same vehicle or freight container unless a numbered exception applies

CLASS or DIVISION	1	2.1	2.2	2.3	3	4.1	4.2	4.3	5.1	5.2	6	7	8	9	Food or food empties	Fire-risk substances or combustible liquids
1 Explosives	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
2.1 Flammable	(1)	YES	YES EXCEPT NOTE (3)	YES	YES EXCEPT NOTE (3)	NO	NO	NO	NO	NO	YES	NO	YES	YES	YES	YES
2.2 Non-flammable non-toxic gas	(1)	YES EXCEPT NOTE (3)	YES	YES EXCEPT NOTE (4)	YES	YES	NO	YES	YES	NO	YES	YES	YES	YES	YES	YES
2.3 Toxic gas	(1)	YES	YES EXCEPT NOTE (3)	YES	NO	YES	NO	YES	NO	NO	YES	YES	YES	YES	NO EXCEPT NOTE (4)	YES
3 Flammable liquids	(1)	YES EXCEPT NOTE (3)	YES	NO	YES	YES	NO	YES	NO	NO	YES EXCEPT NOTE (4)	NO	YES	YES	YES	YES
4.1 Flammable solids	(1)	NO	YES	YES	YES	YES	NO	YES	NO	NO	YES	NO	YES	YES	YES	YES
4.2 Spontaneously combustible	(1)	NO	NO	NO	NO	NO	YES	YES	NO	NO	YES	NO	YES	YES	YES	YES
4.3 Dangerous when wet	(1)	NO	YES	YES	YES	YES	YES	YES	NO	NO	YES	NO	NO	YES	YES	YES
5.1 Oxidising substance	(1)	NO	YES	NO	NO	NO	NO	NO	YES EXCEPT NOTE (4)	NO	YES EXCEPT NOTE (4)	NO	NO	YES EXCEPT NOTE (4)	YES	NO
5.2 Organic peroxides	(1)	NO	NO	NO	NO	NO	NO	NO	NO	YES	YES EXCEPT NOTE (4)	NO	NO	YES EXCEPT NOTE (4)	YES	NO
6 Toxic or infectious substance	(1)	YES	YES	YES	YES EXCEPT	YES	YES	YES	YES EXCEPT	YES EXCEPT	YES	YES	YES EXCEPT	YES	NO EXCEPT NOTE (4)	YES
7 Radioactive material	(1)	NO	YES	YES	NO	NO	NO	NO	NO	NO	YES	YES	NO	YES	NO EXCEPT NOTE (4)	YES
8 Corrosive substances	(1)	YES	YES	YES	YES	YES	YES	NO	NO	NO	YES EXCEPT NOTE (4)	NO	YES EXCEPT NOTE (4)	YES	NO EXCEPT NOTE (4)	YES
9 Miscellaneous DGs	(1)	YES	YES	YES	YES	YES	YES	YES	YES EXCEPT NOTE (4)	YES EXCEPT NOTE (4)	YES	YES	YES	YES	YES	YES

Figure 11: Dangerous Goods Segregation (Source Checklist Templates - Safety Culture iAuditor**)**

7.2 Employees Responsibilities

- Ensure that they are appropriately licenced and authorised to transport the radiation source.
- Report all defects in equipment or packaging that come to their notice and which they believe are likely to cause a radiation exposure or to contribute to one arising.
- Acquaint themselves with and obey all instructions issued to them to protect their safety and the safety of others. This includes securing any consignment against loss either intentional or intentional.
- Refrain from careless or reckless practice or action likely to result in a radiation hazard for themselves or others.
- Use, in a manner required by the statutory authority, devices or equipment furnished to them to assess their personal radiation exposure.
- In the event of an incident, preserve life and contact RSO and/or relevant authorities.

7.3 Types of Packaging

Package shall mean the complete product of the packing operation, consisting of the packaging and its contents prepared for transport. The types of packages covered by these Regulations that are subject to the activity limits and material restrictions of Section IV of the Code for the Safe Transport of Radioactive Material and meet the corresponding requirements are:

- Excepted package.
- Industrial package Type 1 (Type IP-1)
- Industrial package Type 2 (Type IP-2)
- Industrial package Type 3 (Type IP-3)
- Type A package.
- Type B(U) package.
- Type B(M) package.
- Type C package.

Least Stringent

Package design

to

Most Stringent

Package Design

Packages containing fissile material or uranium hexafluoride are subject to additional requirements.

7.3.1 Excepted Packages

Excepted packages are packages in which the allowed radioactive content is restricted to such low levels that the potential hazards are insignificant and therefore no testing is required with regard to containment or shielding integrity. A common example of an excepted package is the postal package used to carry low level radiopharmaceuticals for medical purposes. Refer to Table 6 in Appendix A for more details.

7.3.2 Type A Packages

Are intended to provide a safe, economical means for transporting small quantities of radioactive materials. These are expected to retain their integrity under conditions considered “normal”, that is likely to occur during transport. Figures 12 and 13 shows different examples of Type A Packaging.

Industrial Isotopes are Special form radioactive materials non-dispersible solid or a sealed capsule containing radioactive material. Source capsules are tested to ensure that they meet the IAEA special form requirements. Special form certificates are issued once a sealed source has passed considerable tests and apply to specific manufacturers identification numbers. Always check that the special form certificate has not expired. All other radioisotopes are considered normal form. Radiopharmaceuticals fall into the normal form category.



Figure 12: Radiopharmaceuticals Type A Packaging for Mo^{99} (Decays to Tm^{99}) ANSTO

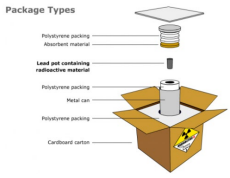






Figure 13: Type A Packaging used for special form materials or sealed source radioisotopes (Nevada Tech, Alemy, Frontier Technology)

Type A packaging must pass the following tests:

- **Water Spray**
  1 hour @ the rate simulating rainfall of 5 cm/h
- **Free Drop Test**
  Packaging < 5000 Kg 1.2m
  5000 Kg to 10 000 Kg 0.9m
  10 000 Kg to 15 000 Kg 0.6m
  Packaging > 15 000 Kg 0.3m
- **Compression Test**
  5 x Weight for 24 hrs.
- **Penetration Test**
  A 6Kg bar, 3.2 cm Diameter, dropped from 1 meter for Solids.

7.4 Type B Packages

Type B packages meet more stringent requirements. Type B packages are designed to withstand very severe accidental conditions in all modes of Transport.

There are two sub-classes of Type B packages: Type B(M) Multilateral and Type B(U) Unilateral.

7.4.1 Type B(M) Multilateral Packages

Type B (M) packages are used to transport Nuclear Fuel Rods. Examples of Type B(M) are shown in Figure 14.



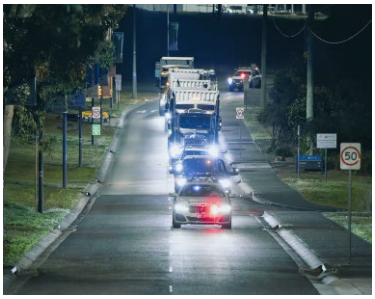


Figure 14: Type B(M) Packages: Nuclear fuel rods (World Nuclear Association, ANSTO)

7.4.2 Type B(U) Unilateral Packages

Type B(U) packages are commonly used to transport Industrial Radiography Sources. The maximum activity is 1000 TBq. When the projector itself is shipped (Centre Figure 15), it is commonly shipped in an overpack to protect it from transit damage.



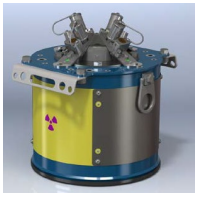


Figure 15: Type B(U) Packages (L-R Bulk Quantity of Ir^{192}/Co^{60}, QSA Radiography Projector, QSA Source Transfer Pod with the locking lid removed) QSA

7.5 Type B Package Tests

- **Mechanical Test**
  - 9 m drop test onto a flat surface.
  - 1 m drop test onto a steel bar (15cm diameter projected 20 cm above the Base)
  - 500 kg steel mass is dropped from 9 m.
- **Immersion Test**
  - At 15 m depth for at least 8 Hours
- **Fire Test**
  - 800° C for at least 30 minutes

7.6 Type C Packages

Type C packages are defined as activity packages greater than 1000 TBq and are designed as over-packs. These are commonly used in bulk Air transport for high activity consignments. The majority of the contents are a propriety energy absorbing compartment (EAC) surrounding the secure central containment cell. Figure 16 shows the cut-away view and typical Type C Package.

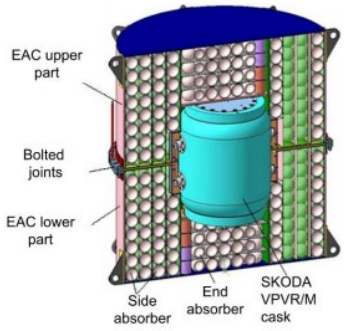




Figure 16: Type C Package Sectional View and secured for Air Transport. (AO SOSNY Research and Development Company)

Testing for Type C Packages are the same as Type B with an additional impact test conducted under conditions, so the impact is equivalent to 90 meters/second. This is similar to a drop from 450 meters. Figure 17 shows a prototype Type C package mounted on a rocket sled for testing.



Figure 17: Type C Impact test (Source AO SOSNY Research and Development Company)

7.7 Bulk Material Transport Package (Low Specific Activity)

Bulk materials such as Uranium Ore is loaded into drums and shipped in a bulk material package and are classed IP1, IP2, IP3 as shown in Figure 18.

These packages are subject to certain tests around:

- Lifting and stowage capability's
- Surfaces designed for de-contamination.
- Protected against unauthorised access.
- Ability to maintain a good seal when subject to changes in pressure and temperature.



Figure 18: Bulk Material Steel industrial Package (World Nuclear Transport Institute)

7.8 Preparing for Consignment

Step 1 is to determine the type of package:

- Excepted Package
- Type A Package (White I, Yellow II or Yellow III)
- Type B(U) Package (Yellow II or Yellow III)
- Overpack used with Type B(U) Consignment

7.8.1 Excepted Package

If it's an excepted package, an un-licenced person may transport the consignment. The following conditions must be met for an excepted package:

- It's an empty package having contained radioactive material.
- Maximum dose rate at the surface of the box is no more than 5 $\mu Sv.h^{-1}$
- Activity is less than excepted package limit (as described in RPS C-2 2019 Table 2) or in cases where there is a mix or unknown radionuclides. Refer to Table 6
- 2 x Radioactive Material, Excepted Package label on opposite side of the Excepted Package. (Refer Figure 19)
- Consignors Declaration for Dangerous Goods is not required for Excepted Package



Figure 19: Excepted Package Label (UN number is found on page 2 of the Dangerous Goods Declaration)

7.8.2 Type A and B(U) Packages

If the surface of the package exceeds 5$\mu Sv.h^{-1}$or the contents activity exceeds the limits as described in Tabel 6.

- Calculate the transport index or TI. (This is required for Yellow II or Yellow III) Refer Table 5 and Figure 20, White 1 does not require a transport index.
- Determine the highest radiation reading at 1m in $\mu Sv.h^{-1}$
    - Divide this by 10 to determine the TI.
    - If the TI is not greater than 0.05, the value quoted may be zero.
    - (If shipment has neutron sources both gamma and neutron levels must be added together)
- Select the correct label and complete the TI, Contents and combined current activity.

- Complete Consignors Declaration for Dangerous Goods.
- Additional documents required:
  - Consignment Note
  - Dangerous Goods Class 7 Form (Figure 21)
  - Packing List
  - Special Form Certificate
  - Source Certificates
  - Transport permit (if required for Security Enhanced Sources)

Transport Index	Radiation Level at Surface of Package	Label Category
Not Applicable	*Not more than 5µSv.h^{-1} Surface*	White – 1
TI 0 - 1	*More than 5µSv.h^{-1} but not more than 500µSv.h^{-1} Surface*	Yellow – II
TI 1 - 10	*More than 500µSv.h^{-1} but not more than 2000µSv.h^{-1} Surface*	Yellow - III
TI > 10	*More than 2000µSv.h^{-1} but not more than 10000µSv.h^{-1} Surface*	Yellow – III Exclusive Use

Table 5: Determining the Transport Index (TI)

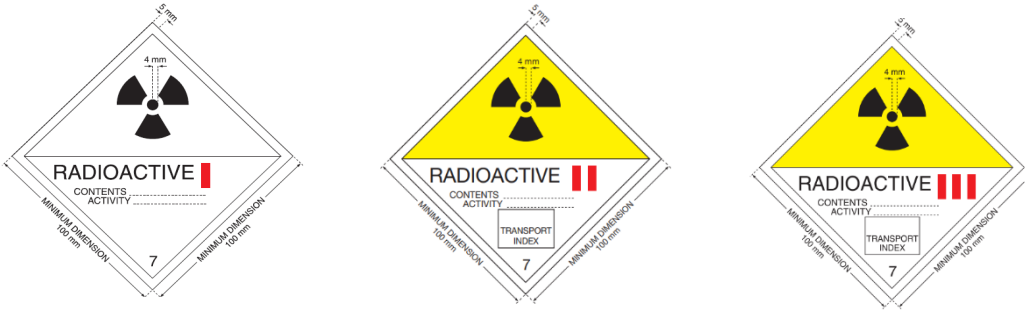


Figure 20 – Class 7 Labels (Category 1 – White, Category II – Yellow and Category III – Yellow) Source: ARPANSA RPS C-2

ROAD/RAIL/INLAND WATERWAYS CONSIGNOR'S DECLARATION FOR DANGEROUS GOODS

CLASS 7 RADIOACTIVE MATERIAL

TWO COMPLETED AND SIGNED COPIES OF THIS DECLARATION MUST BE PROVIDED TO THE CARRIER

CONSIGNOR (SENDER'S NAME AND ADDRESS)	NAME OF TRANSPORTING COMPANY AND CONSIGNMENT No.	CONSIGNEE (RECEIVER'S NAME AND ADDRESS)	INLAND WATERWAYS USE ONLY
MES Unit B07, Harbour City Central Harbour Road Mackay 4740	Paul Thompson (MES) Under Individual Licence CONSIGNOR'S REFERENCE No. Enter Client Job Number/PO Number	Client mine site Local Road Via Closest Town	PORT OF LOADING: DATE OF LOADING: PORT OF DISCHARGE: VESSEL: CONTAINER No:

NATURE AND QUANTITY OF RADIOACTIVE MATERIAL

See applicable Codes: International Atomic Energy Agency (IAEA) — Specific Safety Requirements No. SSR-6 (2012) and the Code for the Safe Transport of Radioactive Material 2014 (Transport Code)

United Nations No.	UN 3332	PROPER SHIPPING NAME (Refer overleaf)	UNITED NATIONS DANGEROUS GOODS CLASS	SUBSIDIARY RISK (if applicable) Classes 1 to 8	RADIONUCLIDE	PHYSICAL AND CHEMICAL FORM	MAX ACTIVITY OF RADIOACTIVE CONTENTS
		RADIOACTIVE MATERIAL, TYPE A PACKAGE, SPECIAL FORM, non-fissile or fissile excepted	7	NIL	Cs137	Special Form	58.5 GBq

CATEGORY OF PACKAGE (I-WHITE II-YELLOW III-YELLOW or N/A)	TRANSPORT INDEX (Definition: 100 times the maximum radiation dose in millisievert per hour (mSv/h) at 1 metre. For Yellow hazard categories only)	CRITICALITY SAFETY INDEX (For fissile material only)	COMPETENT AUTHORITY APPROVAL CERTIFICATE NUMBER(S) (required for special form Ra material, low dispersible Ra material, special arrangement, package design or shipment)	NUMBER OF PACKAGES (information to be repeated for each package)	PACKAGE TYPE (eg. IP-1, IP-2, Type A, B(U))	EXCLUSIVE USE SHIPMENT (Delete category not applicable)	TOTAL ACTIVITY OF THE CONSIGNMENT (for LSA-II, LSA-III, SCO-I or SCO-II only) Multiple of A2
Yellow II	0.4	N/A	US/0703/S96 CZ/1013/S96	1	Type A	☐ YES ☑ NO	N/A

WARNING

FAILURE TO COMPLY IN ALL RESPECTS WITH THE APPLICABLE RADIOACTIVE MATERIALS TRANSPORT REGULATIONS MAY BE IN BREACH OF THE APPLICABLE LAW, SUBJECT TO LEGAL PENALTIES.
THIS DECLARATION MUST NOT, IN ANY CIRCUMSTANCES, BE COMPLETED AND/OR SIGNED BY A CONSOLIDATOR, A FORWARDER OR CARGO AGENT.

I HEREBY DECLARE THAT THE CONTENTS OF THIS CONSIGNMENT ARE FULLY AND ACCURATELY DESCRIBED ABOVE BY THE PROPER SHIPPING NAME AND ARE CLASSIFIED, PACKED, MARKED AND LABELLED, AND ARE IN ALL RESPECTS IN PROPER CONDITION FOR TRANSPORT BY ROAD/RAIL/INLAND WATERWAYS (*check transport mode/s below*) ACCORDING TO THE APPLICABLE INTERNATIONAL AND NATIONAL GOVERNMENTAL REGULATIONS.

NAME OF CONSIGNOR: (PLEASE PRINT) Paul Thompson

POSITION: Radiation Consultant

ROAD ☒ RAIL ☐ INLAND WATERWAYS ☐

SIGNATURE (SEE ABOVE WARNING): .....

DATE: .....

ADDITIONAL HANDLING INFORMATION (e.g. Schedule Number, Special arrangements, Exclusive use, other information)

MES Radiation Safety Officer Mobile: 0400 xxx xxx

SEE REVERSE FOR INFORMATION FOR CARRIERS AND EMERGENCY PROCEDURES

Version Date: March 2017

Figure 21: Example of completed Consignors Declaration for Dangerous Goods Form

7.9 Vehicle Placards.

Any road transport of Class 7 goods (Excluding Excepted Packages) shall display a Class 7 placard on both sides of the vehicle and the rear of the vehicle. (Figure 22)

For bulk shipments this must be displayed on all four sides of the container and a Class 7 Label as described in 7.8.2 may be used as long as it meets the same dimensions shown in Figure 22.

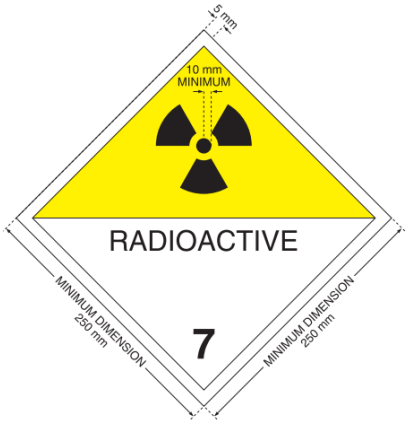


Figure 22: Transport Placard image and dimensions. (ARPANSA RPS C-2)

7.9.1 Transport and Stowage in Transit

Class 7 goods shall be segregated during transport and during storage in transit Category II Yellow or III Yellow packages or overpacks shall not be carried in compartments occupied by passengers:

- From workers in regularly occupied working areas by distances calculated using a dose criterion of **1-6 mSv in a year**. While this is the maximum recommended dose rate where an area monitoring program is in place, individual monitoring may also be implemented. Always strive to keep dose rates as low as reasonably achievable (ALARA) Any dose-rates in excess of 6 mSv in a year require that personal dosimetry is carried out and results recorded.
- From members of the public in areas where the public has regular access by distances calculated using a dose criterion of **1 mSv in a year**.
- Secured during transport to prevent loss. (Figures 23, 24 displays a typical road transport) It is the operators responsibility to ensure that the consignment remains secure.



Figure 23: Typical road transport in a light vehicle. (Note consignment has all documentation attached to the Type A package)



Figure 24: Typical road transport with a trailer. (Note has an overpack and Type A Drum)

Source: MES files

8. ACCIDENTS INVOLVING CLASS 7 CONSIGNMENTS DURING TRANSPORT

YOU MUST ALWAYS ENSURE YOUR SAFETY AND THE SAFETY OF OTHERS.

IN CASE OF ACCIDENT

If a radioactive material package has been damaged, and you suspect that the damage may allow leakage of radiation or spillage of radioactive material:

- Stay away from the package and **do not touch it.**
- Keep other people away from it.
- Notify your supervisor or manager, also inform them of any person who might have been contaminated — they will call for expert technical help if necessary.
- Tell anybody who might have touched the damaged package to report to the supervisor or manager — they will arrange the necessary action.
- Wash your hands thoroughly if you have touched the damaged package or objects near it and tell the supervisor or manager of your possible contamination by radioactive material.
- Have yourself checked for possible contamination before you leave work.
- Note any vehicles involved in the accident — the vehicles should remain at the accident site until cleared by the police or a competent person.
- **Do not** eat or smoke or drink or leave until checked for possible contamination.
- Advise the competent authority of details of the accident as soon as possible and follow any instructions subsequently issued.

Due to the nature of sealed radioisotopes the main hazard is external exposure resulting from the sealed source being exposed from its shielding after an accident. Continuous radiation monitoring during transport will alert personnel in this event.

Accidents involving the release of nuclear medicine is more likely due to the actual containment of the source (glass vials) within a shielded package. Due to low activity of these radioisotopes, external exposure is less hazardous. Debris and contamination can easily be removed and placed in bags and containers and disposed or stored appropriately. Due to the small areas of contamination associated with radiopharmaceuticals and the short-half-life of radioactive substance there is a reduced risk to persons and the environment.

Appendix A Tables

Table 6: Excepted package activity limits for solids only (calculated from ARPANSA Code for the Safe Transport of Radioactive Material RPS C-2, Table 4)

This reference sheet provides the activity limits for excepted packages containing radioactive substances, with activity values in MBq for easy reference. Values are based on the IAEA SSR-6 (Rev.1) and ARPANSA RPS C-2 (2019) Table 2 and Table 4, converted from TBq to MBq (1 TBq = 1,000,000 MBq). Excepted package limits are calculated as 10^{-3} × A1 for special form solids and 10^{-3} × A2 for normal form solids.

Radionuclide	Physical Form	A1 (MBq)	A2 (MBq)	Excepted Package Limit (MBq)
Cs-137	Special form	2,000,000	600,000	2,000
Cs-137	Normal form	2,000,000	600,000	600
Co-60	Special form	400,000	400,000	400
Co-60	Normal form	400,000	400,000	400
Am-241	Special form	10,000,000	1,000	10,000
Am-241	Normal form	10,000,000	1,000	1
Am-241/Be	Special form	10,000,000	1,000	10,000
Am-241/Be	Normal form	10,000,000	1,000	1
Pu-238	Special form	10,000,000	1,000	10,000
Pu-238	Normal form	10,000,000	1,000	1
Cf-252	Special form	100,000	3,000	100
Cf-252	Normal form	100,000	3,000	3
Cm-244	Special form	20,000,000	2,000	20,000
Cm-244	Normal form	20,000,000	2,000	2
U (natural)	Normal form	Unlimited	Unlimited	Unlimited
Th (natural)	Normal form	Unlimited	Unlimited	Unlimited

Table 7: Common prefixes used in radiation protection units.

Prefix	Value	Prefix	Value
kilo (k)	10^{3}	milli (m)	10^{-3}
mega (M)	10^{6}	micro (µ)	10^{-6}
giga (G)	10^{9}	nano (n)	10^{-9}
tera (T)	10^{12}	pico (p)	10^{-12}
example: GBq	$1.0x10^{9}$ becquerels	Example: µCi	$1.0x10^{-6}$ curies

Table 8: Units of radioactivity

Prefix	Value	Definition
SI Unit	becquerel (Bq)	1 (one) radioactive disintegration per second
non-SI unit	curie (Ci)	$3.7x10^{10}$ disintegrations per second

Table 9: Units of Exposure and Dose

SI units		non-SI units	
gray (Gy)	absorbed dose	Rad (R)	absorbed dose
sievert (Sv)	dose equivalent / effective dose	rem	dose equivalent / effective dose

Table 10: Quick activity conversion table.

non-SI	SI	non-SI	SI	non-SI	SI
1 Ci	37 Gbq	5 Ci	185 GBq	10 Ci	370 GBq
1 mCi	37 MBq	5 mCi	185 MBq	10 mCi	370 MBq
1 µCi	37 kBq	5 µCi	185 kBq	10 µCi	370 kBq

Table 11: Quick dose quantity conversion table.

non-SI	SI	non-SI	SI	non-SI	SI
100 rem	1 Sv	500 rem	5 Sv	1000 rem	10 Sv
100 mrem	1 mSv	500 mrem	5 mSv	1 rem	10 mSv
0.1 mrem	0.1 µSv	0.5 mrem	5µSv	1 mrem	10 µSv

Document Control

Revision History

REV	DATE	COMMENT	AUTHOR	APPROVED
1.0	31/01/2024	Establishment of Document	P. Thompson	K. Lawrenson
1.1	12/02/2024	For review	P. Thompson	K. Lawrenson
1.2	05/03/2024	Issued for use	P. Thompson	K. Lawrenson
1.3	01/05/2024	Figure 21 updated	P. Thompson	K. Lawrenson
2.0	13/01/2025	12m Review, QMS Formatting	P. Thompson	K. Lawrenson
2.1	31/10/2025	12m Review, Add table 6, references	P. Thompson	K. Lawrenson