Radiation Assessments

TELLUS

SANDY RIDGE FACILITY
RADIATION WASTE MANAGEMENT PLAN

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Document control

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ABBREVIATIONS

ADT	Articulated Dump Truck
ALARA	As Low as Reasonably Achievable
ARPANSA	Australian Radiation Protection and Nuclear Safety Agency
Bq	Becquerel
Bq/cm^2	Becquerels per square centimetre
Bq/g	Becquerels per gram
Bq/kg	Becquerels per kilogram
Bq/m^3	Becquerels per cubic metre
°C	degrees Celsius
Gv	gray (unit)
HAZOP	hazard and operability
HLW	High level radioactive waste
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
ILW	intermediate level waste
IWDF	Intractable Waste Disposal Facility
L	litre
LLW	low level radioactive waste
m	metre
mSv	Millisieverts
mSv/y	Millisieverts per year
NOHSC	National Occupational Health and Safety Commission
NORM	naturally occurring radioactive material

PPE	personal protective equipment
RWMP	Radiation Waste Management Plan
TC	Transport contractor
TLD	Thermoluminescent Dosimeter
VLLW	very low level waste
VSLW	very short lived waste
WA	Western Australia
WAC	Waste acceptance criteria
µGy/h	micro gray per hour

GLOSSARY

Absorbed dose	Quantity of energy imparted by ionizing radiation to unit mass of matter such as tissue. Unit gray, symbol Gy. 1 Gy = 1 joule per kilogram.
Activity	Attribute of an amount of a radionuclide. Describes the rate at which transformations occur in it. Unit becquerel, symbol Bq. 1 Bq = 1 transformation per second.
Alpha particle	A particle consisting of two protons plus two neutrons. Emitted by a radionuclide.
Anthropogenic	As an adjective - caused by humans. Anthropogenic radiation is radiation caused by human activity.
Atom	The smallest portion of an element that can combine chemically with other atoms.
Atomic mass	The mass of an isotope of an element expressed in atomic mass units, which are defined as one-twelfth of the mass of an atom of carbon-12.
Atomic number	The number of protons in the nucleus of an atom. Symbol Z.
Becquerel (Bq)	See activity.
Beta particle	An electron emitted by the nucleus of a radionuclide. The electric charge may be positive, in which case the beta particle is called a positron.
Cosmic rays	High energy ionizing radiations from outer space. Complex composition at the surface of the earth.
Cosmogenic radionuclides	The cosmic radiation which strikes the earth induces radioactivity in the atmosphere. Most of this radioactivity is very short-lived. Some radionuclides however survive to eventually reach the surface of the earth. Among these are H (tritium), Be (beryllium-7) and C (carbon-14) which has the longest half-life (5730 years).
Decay	The process of spontaneous transformation of a radionuclide. The decrease in the activity of a radioactive substance.
Decay product	A nuclide or radionuclide produced by decay. It may be formed directly from a radionuclide or as a result of a series of successive decays through several radionuclides.
Diagnostic radiology	Term usually applied to the use of x-rays in medicine for identifying disease or injury in patients.
Disposal	In relation to radioactive waste, dispersal or emplacement in any medium without the intention of retrieval.
Dose	General term for quantity of ionizing radiation. See absorbed dose, equivalent dose, effective dose and collective effective dose. Frequently used for effective dose.

Effective dose	The quantity obtained by multiplying the equivalent dose to various tissues and organs by a weighting factor appropriate to each and summing the products. Unit sievert, symbol Sv. Frequently abbreviated to dose.
Electromagnetic field	The region in which electromagnetic radiation from a source exerts an influence on another object with or without there being contact between them.
Electromagnetic radiation	Radiation that can be considered as a wave of electric and magnetic energy travelling through a vacuum or a material. Examples are gamma rays, x-rays, ultraviolet radiation, light, infrared radiation and radiofrequency radiation.
Electromagnetic spectrum	All electromagnetic radiations displayed as a continuum in order of increasing frequency or decreasing wavelength.
Electromagnetic wave	See electromagnetic radiation.
Electron	An elementary particle with low mass, 1/1836 that of a proton, and unit negative electric charge. Positively charged electrons, called positrons, also exist. See also beta particle.
Electron volt	Unit of energy employed in radiation physics. Equal to the energy gained by an electron in passing through a potential difference of 1 volt. Symbol eV. 1 eV = 1.6 × 10-19 joule approximately.
Element	A substance with atoms all of the same atomic number.
EMF	Electromagnetic field. Not to be confused with the initials for electromotive force.
Equivalent dose	The quantity obtained by multiplying the absorbed dose by a factor to allow for the different effectiveness of the various ionizing radiations in causing harm to tissue. Unit sievert, symbol Sv.
Excitation	A process by which radiation imparts energy to an atom or molecule without causing ionisation. Dissipated as heat in tissue.
Fission	Nuclear fission. A process in which a nucleus splits into two or more nuclei and energy is released. Frequently refers to the splitting of a nucleus of uranium-235 into two approximately equal parts by a thermal neutron with emission of other neutrons.
Free radical	A grouping of atoms that normally exists in combination with other atoms but can sometimes exist independently. Generally very reactive in a chemical sense.
Frequency	The number of complete cycles of an electromagnetic wave in a second. Unit hertz, symbol Hz. 1 Hz = 1 cycle per second.
Gamma ray	A discrete quantity of electromagnetic energy without mass or charge. Emitted by a radionuclide. See x-ray.
Gray	See absorbed dose.
Half-life	The time taken for the activity of a radionuclide to lose half its value by decay. Symbol t½.

Infrared radiation	Electromagnetic radiation capable of producing the sensation of heat and found between light and radiofrequency radiations in the electromagnetic spectrum. Has subregions IRA, IRB and IRC.
Instability	Having the property of being unstable.
Ion	Electrically charged atom or grouping of atoms.
Ionisation	The process by which a neutral atom or molecule acquires or loses an electric charge. The production of ions.
Ionising radiation	Radiation that produces ionisation in matter. Examples are alpha particles, gamma rays, x-rays and neutrons. When these radiations pass through the tissues of the body, they have sufficient energy to damage DNA.
Isotope	Nuclides with the same number of protons but different numbers of neutrons. Not a synonym for nuclide.
Laser	Device which amplifies light and usually produces an extremely narrow intense beam of a single wavelength.
Light	Electromagnetic radiation capable of producing the sensation of vision and found between ultraviolet and infrared radiations in the electromagnetic spectrum.
Mass number	The number of protons plus neutrons in the nucleus of an atom. Symbol A.
Molecule	The smallest portion of a substance that can exist by itself and retain the properties of the substance.
Neutron	An elementary particle with unit atomic mass approximately and no electric charge.
Non-ionising radiation	Radiation that does not produce ionisation in matter. Examples are ultraviolet radiation, light, infrared radiation and radiofrequency radiation. When these radiations pass through the tissues of the body they do not have sufficient energy to damage DNA directly.
Nucleus	The core of an atom, occupying little of the volume, containing most of the mass, and bearing positive electric charge.
Nucleus of a cell	The controlling centre of the basic unit of tissue. Contains the important material DNA.
Photon	A quantum of electromagnetic radiation.
Positron	See beta particle.
Probability	The mathematical chance that a given event will occur.
Proton	An elementary particle with unit atomic mass approximately and unit positive electric charge.
Radiation	The process of emitting energy as waves or particles. The energy thus radiated. Frequently used for ionizing radiation except when it is necessary to avoid confusion with non-ionizing radiation.
Radioactive	Possessing the property of radioactivity.

Radioactive waste	Useless material containing radionuclides. Categorised in according to activity (and other criteria such as half-life) as exempt, low level, intermediate level and high level waste.
Radioactivity	The property of radionuclides of spontaneously emitting ionizing radiation.
Radiofrequency radiation	Electromagnetic radiation used for telecommunications and found in the electromagnetic spectrum at longer wavelengths than infrared radiation.
Radiological protection	The science and practice of limiting the harm to human beings from radiation.
Radionuclide	An unstable nuclide that emits ionizing radiation.
Radiotherapy	Term applied to the use of radiation beams for treating disease, usually cancers, in patients.
Risk	The probability of injury, harm or damage.
Risk factor	The probability of cancer and leukaemia or hereditary damage per unit equivalent dose. Usually refers to fatal malignant diseases and serious hereditary damage. Unit Sv-1.
Sensitive receiver	Can be a natural feature, such as a water source, a rare, threatened or endangered flora or fauna. It can also be a human feature such as a school or a hospital.
Sievert (Sv)	See effective dose.
Specific energy absorption rate	The rate at which energy is absorbed by unit mass of tissue in an electromagnetic field. Unit watt per kilogram, symbol W kg-1.
Stable	An isotope or nuclide is considered stable if it has a half-life longer than the age of the universe i.e. a half-life longer than about 13.7 billion years.
Ultraviolet radiation	Electromagnetic radiation found between x-rays and light in the electromagnetic spectrum. Has subregions UVA, UVB, UVC.
Unstable	An isotope or nuclide is considered to be unstable if it has a half-life less than the age of the universe i.e. a half-life less than about 13.7 billion years.
UV radiation	See ultraviolet radiation.
Visible radiation	See light.
Waste management	The control of waste from creation to disposal.
Wavelength	The distance between successive crests of an electromagnetic wave passing through a given material. Unit metre, symbol m.
X-ray	A discrete quantity of electromagnetic energy without mass or charge. Emitted by an x-ray machine. See gamma ray.

1 SCOPE

This Radiation Management Plan (RMP) has been prepared to document management systems and procedures to be implemented at the Tellus Holdings Ltd (Tellus), Sandy Ridge waste disposal project to mitigate the risks associated with radioactive waste. This will include details of how radioactive waste is handled, stored and monitored in accordance with relevant legislation and policies.

The RMP has been prepared to address the regulatory requirements of the:

- *Australian Radiation Protection and Nuclear Safety (ARPANS) Act 1998*.
- Australian Radiation Protection and Nuclear Safety Regulations 1999.
- *Radiation Safety Act 1975*.
- Radiation Safety (General) Regulations 1983.
- Radiation Safety (Qualifications) Regulations 1980.
- Radiation Safety (Transport of Radioactive Substances) Regulations 2002.

It also acknowledges the *Nuclear Waste Storage and Transportation (Prohibition) Act 1999*.

2 INTRODUCTION

Tellus is planning to develop the Sandy Ridge Project (the Proposal). The Proposal is comprised of two main business components, mining of kaolin clay for export and storage and permanent isolation (disposal) of hazardous and intractable waste in mine voids.

The proposed commodity business involves mining kaolin mostly in an open cut methodology, processing on site and then exporting the kaolin via Fremantle Port to Asia where it would be used in various industrial sectors (e.g. paper, ceramics, fiberglass and paint). Kaolinite is a clay mineral also known as 'Kaolin clay', with the chemical composition $Al_2Si_2O_5(OH)_4$.

The waste aspect of the Proposal involves disposing of up to 100,000 tpa of intractable, hazardous and low level radioactive wastes in the mine voids (herein referred to as 'cells') over a 25 year period (i.e. 2,500,000 tonnes in total). The conceptual infrastructure layout of the waste disposal

Tellus recognised Australia's need for an operational geological repository; which is able to store intractable and hazardous wastes long-term, rather than having wastes stored in more than 100 locations across Australia, often in unsecured and temporary locations.

Cells would be filled in layers with multiple sections in each layer. Each layer would be divided into sections containing wastes of similar characteristics. Each section would be backfilled, compacted and all air pockets/voids excluded. Each layer would be compacted, until approximately 7m below the ground surface, where a thick capping layer of low permeability clay would be installed to prevent water ingress into the cell. Following this, more backfilling and a clay domed cap would be situated on the top of the cell, to shed any landing rainfall. During the waste disposal process, a roof canopy is positioned over the cell to exclude rainfall prior to the thick capping layer being installed.

Waste acceptance criteria (WAC) developed for this facility is described in the waste acceptance criteria (document reference: TCO-5-05). The radionuclide concentration limits is set taking into account the actual siting, design and planning of the facility (e.g. Natural geological barrier, arid climate, remoteness, engineered multi layered shielding and barriers, duration of institutional control, site specific management plans and operating procedures) and exposure dose constrains to ensure no person is exposed above the dose limit (as defined in Schedule I of the Radiation Safety (General) Regulations). These radioactive wastes are generally generated by medical research and industry, operation of research facilities (e.g. laboratory coats, overshoes, gloves), Naturally Occurring Radioactive Materials (NORMs), NORMs occurring on pipework and scale from industry, oil spills containing NORMs and orphan sources (i.e. gauges and instrumentation). Wastes which would not be disposed of into cells include: infectious materials, nuclear material, uncertified waste, putrescible waste and gases.

Tellus operations are underpinned by utilising a combination of engineered and natural barriers, known as a multi barrier system, which provides long term containment and isolation of the waste.

After the placement of waste in the cell has been completed, the following protection measures would be implemented:

- An all-weather cover would be maintained over the cell until it is backfilled and capped to allow for protection from all weather conditions, without the possibility of creating leachates or contaminated surface water.
- Any airspace surrounding the placed waste would be backfilled with kaolin processing plant waste product (low value kaolin and quartz sand) to fill all void space and provide stability.
- The cell would then be backfilled with compacted clay, silcrete, laterite and yellow sand.
- The surface of the cell would be covered with a domed clay cap to exclude rainfall.

After a period of subsidence monitoring to confirm the stability and integrity of the clay capping, topsoil would be placed over the cap and the area re-vegetated with species of local provenance. Local species would be selected based on their root system penetration (depth), ensuring that the capping design is not compromised.

Tellus would monitor and manage the site for an extended period following closure before returning ownership to State, a period termed institutional control. Further information on management of the Facility is provided in the Waste Facility Decommissioning and Closure Plan.

The institutional control period (ICP) will ensure the wastes stored and disposed of in the geological repository are undisturbed for a period of time until they no longer pose a risk to human health and the local environment.

Figure 2-1 Infrastructure area conceptual layout

2.1 Location

The Proposal is located approximately 75 kilometres (km) north-east of Koolyanobbing, Western Australia. Access is via a 100 km road to the Intractable Waste Disposal Facility (IWDF) Mount Walton East (Crown Reserve No. 44102) that extends northward from the Boorabbin Siding on Great Eastern Highway; a 4.5 km westwards section along an existing road; and a 5.3 km northwards section of new site access road into the development envelope (See Figure 2-2)

There are no sensitive receptors within 5 km of the location of the Proposal. The nearest operation is the Class V IWDF Mount Walton East located approximately 6 km to the east, which operates on a campaign basis and does not have permanent residents. The nearest mining camp is the Carina Iron Ore Mine Accommodation Camp located approximately 52 km to the south east of Sandy Ridge.

The location of the Sandy Ridge Project has been specifically chosen to meet the requirements of International and National codes relating to the siting of a near surface geological repository. These site characteristics include:

- **Geologically stable** — the development envelope sits within the Archean Yilgarn Block and is geologically typical of areas overlying deeply weathered granite domes. It has very low seismicity (no earthquakes have been recorded at Sandy Ridge) and no volcanic or tectonic activity.
- **Natural geological barrier** — the clay bed is laterally extensive (80 km long and 40 km wide), has been stable for approximately 20 million years and is up to 36 m thick. This is capped by erosion resistant silcrete and laterite layers typically 4 to 6 metres thick in total.
- **Semi-arid desert Mediterranean climate** — averages just over 250 mm of rainfall per annum and evaporation is greater than 2,000 mm per annum. This means very little rainfall occurs across the site and generally water will evaporate before it infiltrates.
- **No surface water receptors** - there are no channels or creeks in the development envelope.
- **Very little (if any) surface water runoff** – Due to the low rainfall, high evaporation, permeable upper soil profile and gently sloping topography, significant rainfall events infiltrate quickly. There is a low likelihood of surface flows in the local catchments and any flows are short-lived and local in nature.
- **Lack of commercial mineral deposits** – there is no evidence to suggest that there is potential for economic mineral or hydrocarbon deposits beneath the kaolin deposit.
- **Topography** – the development envelope is flat to gently undulating and suitable for the construction of infrastructure and heavy vehicle movement.
- **Absence of Population** – located in an area with no population, the nearest population centre is a non-permanent camp approximately 52 km away.
- **Agricultural land use** – there is no potential for medium to high value agriculture.

- **Environmental values** – the environmental values of the development envelope are currently unknown and will be determined through investigation.
- **Heritage** – no special cultural or historical significance has been identified through a completed heritage study and consultation with stakeholders familiar with the area.
- **No flooding** – the development envelope is not subject to flooding, nor is it predicted to be in the future. The site is at very low risk of encountering cyclones.
- **Very low rates of erosion** – the development envelope is not subject to the erosive forces of high winds or rain due to the climate, soil types and topography and has been stable for thousands of years.

2.2 Access to appropriate technical expertise, facilities and operating procedures

Tellus Holdings has engaged Hygiea Consulting to provide technical expertise and support for the radiological aspects of the project. Henriette Rossouw; Hygiea Principal Consultant has over 12 years' experience in radiation protection and has been involved in the provision of radiological services to the mining, government and industrial sectors in the Commonwealth and State regulatory framework. Support will include:

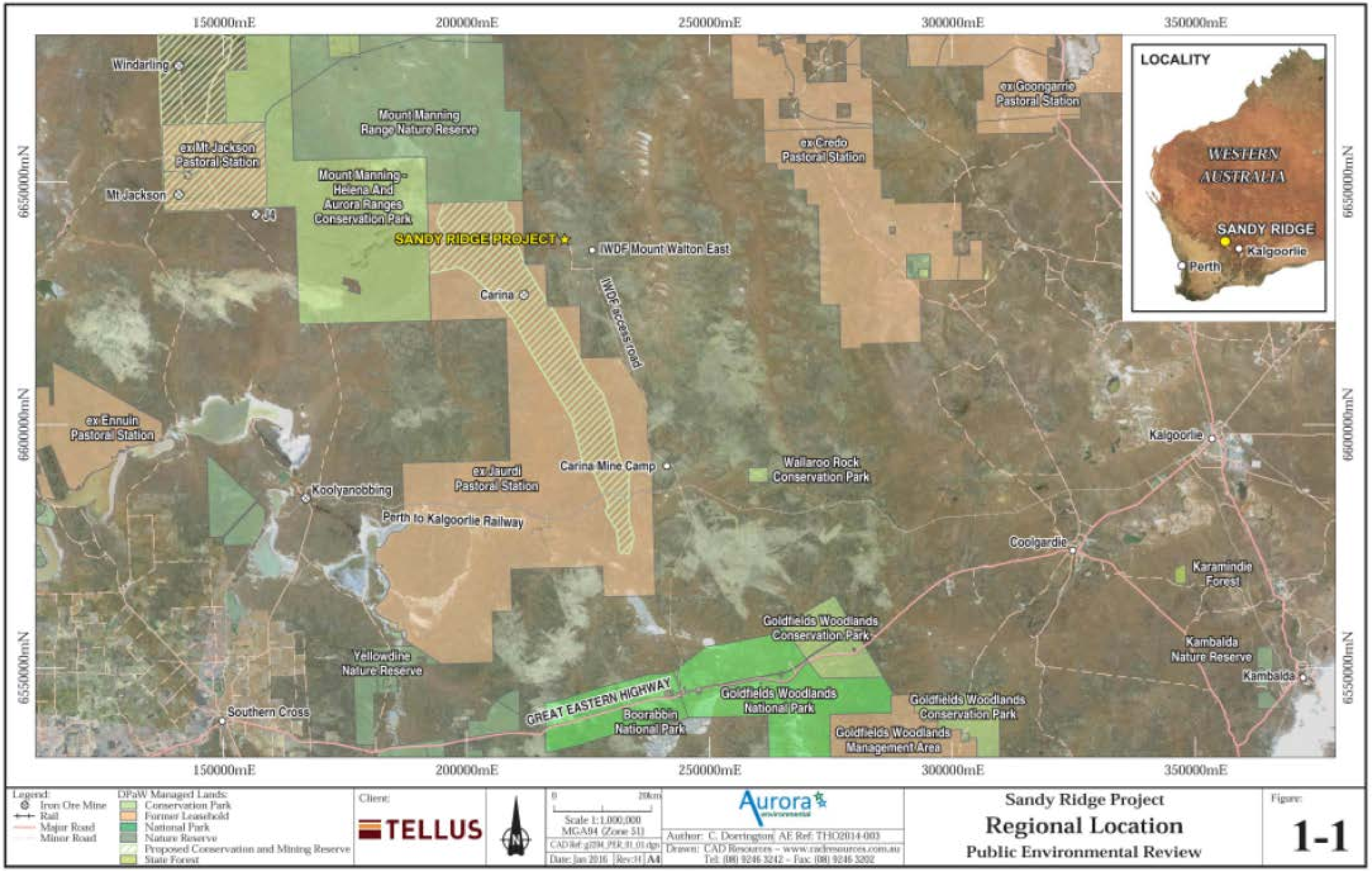
- Acting as Radiation Safety Officer.
- Assistance in preparation of reports and documentation.
- Provision of advice on monitoring equipment, programs and data interpretation.
- Development of systems and procedures relating to radiation safety.
- In co-operation with other consultants, undertake background, environmental and occupational monitoring.

With respect to non-radiological issues Tellus has employed or retained through consultancy agreements a wide range of technical personnel with considerable experience in all aspects of the proposed project.

Equipment used for the evaluation, measurement and assessment of radiological impacts would be provided by Tellus. The equipment would be either, owned and maintained by Tellus, or hired or provided by sub-contractors.

Documented operating procedures, work instructions and maintenance and calibration procedures would be provided in accordance with Tellus documentation policy prior to the commencement of any work.

Figure 2-2 Site location map



3 SYSTEM OF RADIATION MANAGEMENT

3.1 Introduction

The system of radiation management during operation of the proposed Facility is based on the justification, optimisation and limitation principles established by the International Commission on Radiological Protection (ICRP), standardized by the International Atomic Energy Agency (IAEA) and adopted in a joint Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) and National Occupational Health and Safety Commission (NOHSC) document.

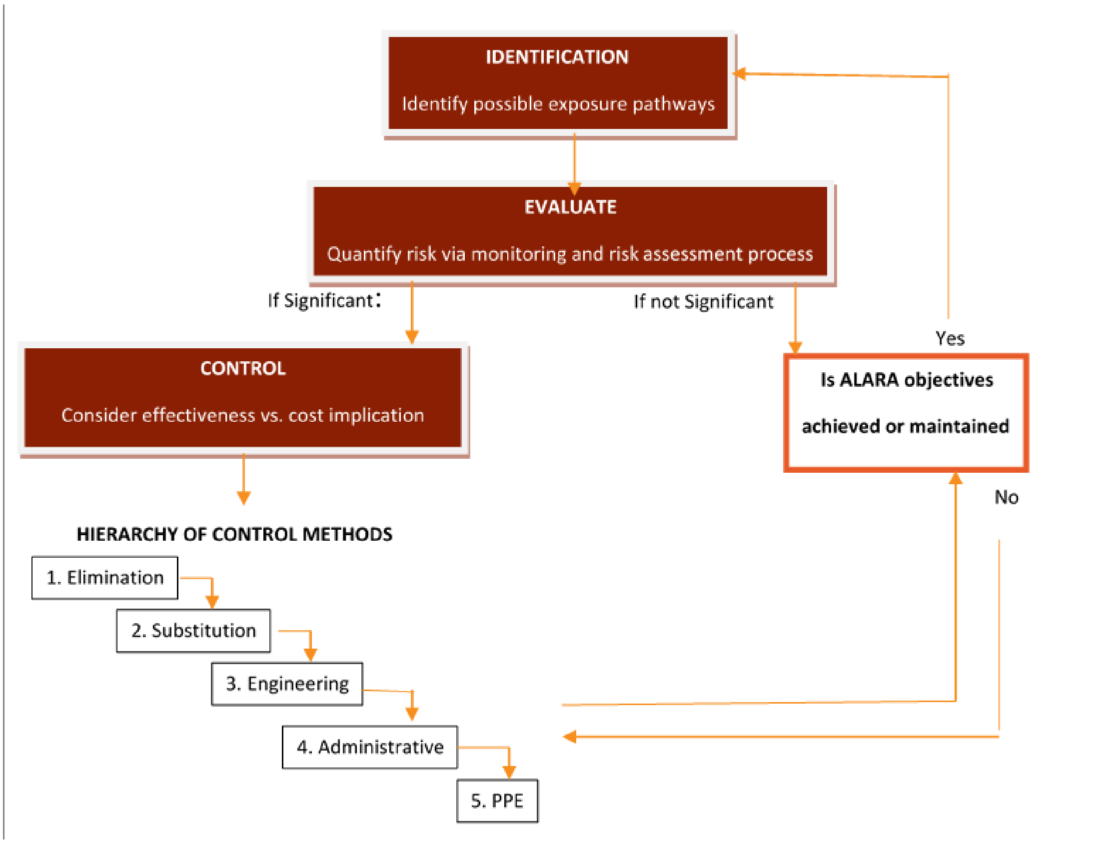
The application of the system and the justification, optimisation and limitation principles are discussed below.

The primary steps in the radiation management process include:

- Identifying and quantifying the sources of radiation.
- Defining possible candidate radiation protection that would reduce the exposure or doses.
- Quantifying the economic factors (cost of systems, operations, maintenance).
- Quantifying exposures and doses to individuals and to populations in the vicinity of the facility.
- Estimating the health risk and identifying non-health detriment.
- Selecting the candidate radiation protection systems or combination of systems with the preferred ALARA (As Low as Reasonably Achievable) outcome.

These steps are illustrated in Figure 3-1 below.

Figure 3-1 System of radiation management



3.2 System process

3.2.1 Justification of the Practice

Tellus recognises that a practice involving exposure to radiation should be adopted only if the benefits of the practice outweigh the risks associated with the radiation exposure. Any decision that alters the radiation exposure situation should do more good than harm. The Justification Principle has been adopted in the design of the facility, control systems and administrative procedures.

3.2.2 Optimisation of protection

Protection from radiation was aimed to keep the likelihood of incurring exposures, the number of people exposed, and the magnitude of their individual doses as low as reasonably achievable, taking into account economic and societal factors (ALARA principle).

The principle of optimisation of radiation protection is a cornerstone of the system for radiation protection and is the key driver for ensuring that radiation doses are not just maintained below standards, but are kept to the lowest feasible level throughout the life cycle of a practice involving radioactive materials.

Optimisation commenced at the design stage of the project. At the design stage, the cost-benefit analysis was conducted to achieve a balanced design, which is not only optimised for radiation protection, but all other health, safety and environmental requirements.

In design, optimisation will be facilitated by:

- Specifying the radiation protection design criteria in terms of dose action levels at 50% of derived limits.
- Specifying engineering control features, such as dust extraction and or suppression equipment, radon gas control, shielding, facility design, roster systems and automation of processes.
- Undertaking formal hazard assessments, such as hazard and operability (HAZOP) studies at various stages of design.
- Ensuring design engineers were aware of relevant radiation protection measures through appropriate training and instruction.
- Applying the hierarchy of risk control principles (i.e. preference to elimination and control of hazards rather than use of operational procedures and PPE) to achieve exposure control.

Some of the administrative operational principles used for optimization involve the:

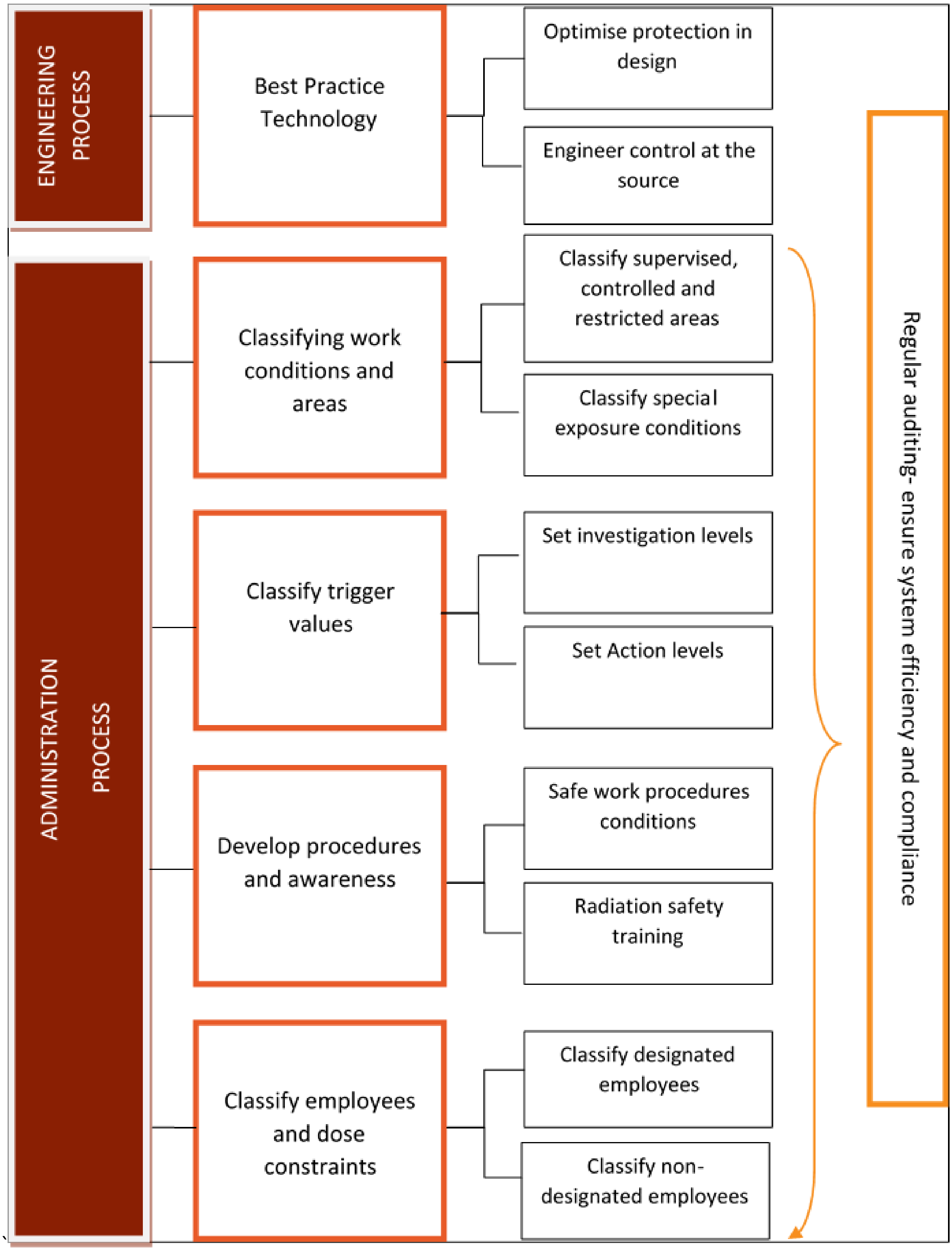
- Classification of working conditions and workplaces.
- Implementation of a risk based radiation monitoring program.
- Application of a recording, analysing and reporting system for the results of the radiation monitoring program.
- Formulation, distribution and implementation of adequate descriptions for the safe conduct of certain work procedures.
- Audit of system to ensure it is efficient in reducing the exposures.

3.2.3 Dose limitation in occupational protection

Individuals should not receive radiation doses greater than the recommended limits. To ensure the dose limits are below the dose limits recommended by the ICRP, ARPANSA and NOHSC an action level of 50% of the stated dose limit was established and used as a design specification.

The diagram in Figure 3-2 Application of system protection illustrates the overall approach that would be followed to ensure that radiation doses at the site are is low as practicable.

Figure 3-2 Application of system protection



4 FACILITY DESIGN

During the feasibility stage of the project consideration were given to engineering best practice as well as socio economic considerations to determine the most suitable design that would meet the safety requirements at acceptable cost. The current proposal is open cut pit with In-cell vertical shaft disposal of radioactive wastes. During the waste disposal process a roof canopy is positioned over the cell to exclude rainfall prior to the capping layer being installed. There may be instances (for non-soluble waste types) where a cell may be filled with waste without a roof canopy. In addition, any potential stormwater surface flows would be diverted away from the cells by bund walls or levee banks.

4.1 Design considerations

The location and design of the mining operations is primarily driven by the requirements of the waste cell.

The design criteria for the open cut mine were:

- Fit within the available span of the covering clear-span building (65 m).
- Cells to be arranged in parallel lines, so as to simplify the relocation of the cover building between pits on lightweight rails.
- Sufficient but minimum separation distance between cells (approximately 20m) to maximise kaolin resource recovery but also allow independent and safe waste and mining activities in adjacent pits.
- Be of maximum available depth, the limiting depth being 5m above un-weathered granite or 30 metres, whichever comes first. Maximising the depth increases the storage capacity and decreases the overburden mining and backfill and capping completion costs per tonne of waste.
- Have the capacity to contain approximately 50,000 tonnes of waste materials. This is not an essential criteria as the length of the covering building is not set, however it does make for easier planning at feasibility study level.
- Ramp access by 40 tonne capacity six wheel drive articulated dump trucks (ADT) and a 30 tonne articulated dump truck carrying a 20 foot ISO container.
- As much of the ramp to be contained within the building footprint as possible, to prevent the ramp becoming a rainfall catchment.
- Safe batter angles for short-term use (<15 months).
- Depth of final cover and capping is based on the existing IWDF practices and near-surface water modelling conducted by Cymod Systems.

- Maximising the availability of kaolin ore.
- Only one mining pit in operation at a time and the pit being left open for as short a time as reasonably practical, as it would be a collection point for rainfall and potential water infiltration.

No detailed site-specific geotechnical data is available yet, but a limited amount of data from the IWDF site investigations and knowledge of similar deep weathering profiles in Western Australia was used to establish the geotechnical parameters for the design. The Design of the cell is illustrated in Figure 4-1..

Figure 4-1 Covered cell design

4.2 Waste storage and isolation business

From a waste storage and isolation perspective (ignoring kaolin sales), there is a vast amount of area with suitable geology for waste placement at Sandy Ridge. The only limits on the amount of area suitable for storage is tenure; a few areas of thicker silcrete (increasing mining costs); or thin kaolinisation. The area of disturbance being applied for with the EPA at present is probably capable of accepting 100 years of waste placement at 50,000 tonnes per year. This could easily be further expanded with additional permitting to accept a further 100 plus years of waste at the same rate per year, and beyond if required.

A solution identified for the storage of radioactive wastes which cannot be placed in an open-cell with other chemical wastes is the construction of shafts within the planned open-cell storage. As demonstrated by Figure 4-2., a number of shafts can be constructed within a cell using pre-formed cylindrical shaft segments. As the cell is progressively filled with other wastes, more segments are stacked upon each other to create a shaft. A buffer of compacted kaolinised granite is placed around each segment to provide further isolation from chemical waste at the same level.

Figure 4-2 In-cell vertical shafts shown in bottom right hand corner

Waste can be placed into the shaft at any time, but it is expected that the shaft would progress to several metres of depth before a campaign of waste placement takes place, so as to provide a level of physical separation and a shield between the radioactive waste and workers on the active surface. Waste drums are lowered into the shaft and each later is backfilled with earthen material to fill void spaces. Higher activity wastes can be backfilled with cementitious slurry if required. A fabricated steel or pre-cast concrete lid is used on the shaft to prevent un-authorised human entry. Upon the shaft reaching and being filled with waste to the base of cap level, the lid is left in place and the structure is covered by the cell cap materials.

Once all wastes are placed in the cell and the area is ready for closure, an engineered cap consisting of compacted backfill materials is placed into the remaining void. This cap serves several purposes; preventing surface or meteoric water from entering the waste storage area and mobilising soluble waste chemicals, preventing erosion, acting as a barrier to un-authorised access of the isolated waste materials, and providing a barrier to radioactive emissions. The construction of the cap is completed by an earthmoving contractor whilst new waste placement activities occur in the next cell. After a monitoring period (currently being negotiated), further overburden and soils are placed over the cap and progressive rehabilitation commences.

The long term (10,000 plus years) performance of the cap has been modelled using both near-surface hydrogeological and erosion modelling software. The modelling has indicated that the cap design is robust from both water infiltration and erosion aspects.

4.3 Mine rehabilitation

Rehabilitation is progressive during the life of the facility Monitoring of the clay caps over each cell takes place for a period before the final placement of any surplus overburden, sub-soil and topsoil over the cap. The soil is then revegetated.

At completion of the project, the infrastructure is removed and the remainder of the site rehabilitated in accordance with normal mine-closure practices.

4.4 Security

The facility security design will be in accordance with ARPANSA RPS 11 in order to decrease the likelihood of the unauthorised access to or acquisition of the radioactive source by persons with malicious intent.

This includes:

- Source security plan would be developed and implemented based on the category of source that requires storage.
- Entire site is security fenced.
- Radiation store building would be physically secure to prevent un-authorised entry
- Access control system to radiation store. (Unique swipe cards required for entry, recording who/when entered.)
- Exterior surveillance cameras on the Radiation Store building that would be linked to a remote recording system.
- Cameras and alarm system on the Radiation store building would be linked to on site office location as well as the accommodation village 3 km away to raise an alarm. Response on alarm would be attended to by trained person from accommodation village if the working site is not manned at the time.
- During site induction all workers on site and Responsible Person are made aware of security issues and response procedures would be developed in accordance with guidelines (RPS 11).

5 WASTE MANAGEMENT

5.1 Waste types accepted

Intractable wastes do not have commercially viable recycling, reuse or disposal options and include wastes that need time to breakdown and chemical wastes that are not readily destroyed. These wastes need long-term management. The Facility provides a location where intractable wastes can be permanently isolated to protect the community and the environment.

Likely chemical wastes to be disposed of in the cells include; arsenic or arsenic containing compounds, cyanide inorganic compounds, chromium (VI) compounds, lead or lead compounds, spent pot liners, soils contaminated with heavy metals, asbestos and pesticides, hydrocarbon wastes and phosphates from the agricultural industry.

The type of industrial materials to be stored or permanently isolated are intractable and hazardous materials generated in the; mining, oil and gas, heavy industry, agricultural and government (emergency service) sectors.

Examples of wastes that may be accepted at Sandy Ridge include:

- **Mining Industry**
  - Waste process streams, e.g. arsenic from the gold industry.
  - Demolition waste produced during the decommissioning of mining and processing radioactive ore operations, such as pipework, concrete, machinery and PPE.
- **Oil and gas** — for example hydrocarbons in contaminated soil or from processing from upstream, midstream and downstream. Note: some waste from the oil and gas industry contains naturally occurring radioactive materials (NORMs). NORM containing scale and equipment would be accepted at the facility.
- **Heavy industry** — For example spent catalyst wastes (Aluminium slag).
- **Agricultural** — for example pesticides.
- **Government** (state emergency service) — waste generated due to man-made or natural disasters that need to be removed safely by Government out of the community. For example - asbestos clean ups.
- **Medical isotopes** — those used in medical research, equipment, contaminated PPE and X rays used by dentists/doctors.
- **Industrial radioactive equipment** – such as grain moisture meters, smoke alarms and gauges.

The classification of radioactive waste has been defined in international standards developed by the IAEA. ARPANSA Safety Guide for Classification of Radioactive Waste (2010) largely reflects the international guidance referred to above. As such, it does not include quantitative values of allowable activity content for each significant radionuclide. Radioactive waste generated in Australia generally falls within the Very Short Lived Waste (VSLW), Very Low Level Waste (VLLW), Low Level Waste (LLW) or Intermediate Level Waste (ILW) classifications. Australia does not generate any electricity from nuclear power and therefore currently does not generate any used fuel that would be classified as High Level Waste (HLW).

Waste acceptance criteria (WAC) developed for this facility is described in the waste acceptance criteria document. The radionuclide concentration limits is set taking into account the actual siting, design and planning of the facility (e.g. Natural geological barrier, arid climate, remoteness, engineered multi layered shielding and barriers, duration of institutional control, site specific management plans and operating procedures) and exposure dose constrains to ensure no person is exposed above the dose limit (as defined in Schedule I of the Radiation Safety (General) Regulations).

5.1.1 Industrial and medical radioactive source

A sealed radioactive source is a container of encapsulated radioactive material. The capsule or material of a sealed source is strong enough to maintain leak tightness under the conditions of use for which the source was designed, and also under foreseeable mishaps. In more technical terms, it is radioactive material that is:

- Permanently sealed in a capsule or;
- Closely bonded and in a solid form.

The source is designed to contain the radioactive material under normal operating conditions and, usually has high concentration of radioactive material in a small volume.

Sealed radioactive sources are used in various applications in medicine, agriculture, industry, transportation, construction, geology, mining, research, etc. For example high activity cobalt sources are used to treat cancer. In most of these areas the use of sealed radioactive sources either cannot be replaced by other methods or provides results that are unmatched by other methods.

Radioactive sources with half-lives of less than about 100 days will decay to safe levels in a few years. From a waste management point of view such sources can be safely allowed to decay in storage or in near surface disposal facilities. This does not mean that short half-life radioactive sources are without hazard. The radionuclides in the strongest source category (Co_{60}, Sr_{90} and Cs_{137}) are those with moderate half-lives between about 5 and 30 years. With such high strengths and moderate half-lives these sources require isolation for hundreds to thousands of years. Sources used for the calibration of instruments may contain extremely long lived radionuclides such as C_{14} (half-life = 5700 years), Cl_{36} (half-life = 300 000 years) and I_{129} (half-life = 17 million years), but their activity is generally low and of negligible radiological significance.

Table 5-1 summarises such radioisotopes relevant to the medical and industrial sectors.

Table 5-1 Industrial and medical radioisotopes

Isotope	Half Life	Common uses
Radioisotopes commonly used in medical and laboratory settings		
Americium 241	432 years	Research. Check source for instruments
Caesium 137	30.1 years	Irradiators. Teletherapy. Brachytherapy. Check source for instruments and Cameras. Also used in radiotracing to identify sources of soil erosion and depositing, also for nuclear gauges.
Carbon 14	5730 years	Used to measure the age of organic material, diagnose certain bacteria in people.
Chromium 51	27.71 days	Chromium [Cr_{51}] Edetate Injection BP is used to determine the amount of fluid flowing through your kidneys (glomerular filtration rate) and to assess the function of your kidneys. Sodium Chromate [Cr_{51}] Sterile Solution BP is used for in-vitro/ex-vivo red blood cell labelling and is intended only for diagnostic use.
Cobalt 60	5.27 years	Irradiators. Teletherapy. Industrial Radiography. Brachytherapy.
Copper 64	12.7 hours	Used to study genetic disease affecting copper metabolism.
Fluorine 18	110 min	Used in Positron Emission Tomography (PET) to study brain physiology and pathology, detect heart problems and diagnose certain types of cancer.
Gallium 67	78.3 hours (3.26 days)	Infection scans, the most common use is to investigate whether there is an area of localised infection in the body or to detect the location of certain types of tumours.
Gold 198	2.696 days	Wire implants for cancer therapy. Can be used to trace sewage and liquid waste movements.
Iodine 123	13.2 hours	Used in imaging to monitor thyroid function and detect adrenal dysfunction.
Iodine 125	59.4 days	Brachytherapy. Used for treatment of thyroid diseases and cancer and scanning.
Iodine 131	8 days	Used for treatment of thyroid diseases and cancer and scanning.
Iridium 192	74 days	Industrial Radiography. Brachytherapy. Supplied in wire form for use as an internal radiotherapy source, also used as a radiography source.
Molybdenum 99	66.02 hours	Used as the ‘parent’ in a generator to produce technetium 99m
Phosphorus 32	14.28 days	Used most commonly in the treatment of Polycythemia Rubra Vera. I.e. an overproduction of red blood cells. Labelling DNA.
Phosphorus 33	19 days	RTGs. Labelling DNA
Plutonium 238	87.8 years	Pacemakers.
Radium 226	1600 years	Brachytherapy.

Samarium 153	46.7 hours	Used to help in relieving the pain caused by tumour deposits in the bone
Selenium 75	120 days	Industrial Radiography
Sulphur 35	87.2 days	Labelling DNA
Strontium 90	28.6 years	RTGs Used for pain relief therapy for men with the spread of bone cancer (metastases)
Tritium	12.32 years	Measure the age of young groundwater and used as a tracer to study sewage and liquid wastes. Labelling in labs.
Technetium 99m	6 hours	Used to image the brain, thyroid, lungs, liver, spleen, kidney, gall bladder, skeleton, blood pool, bone marrow, salivary and lachrymal glands and heart blood pool and to detect infection. Can be used to trace sewage and liquid waste movements.
Thallium 201	73.1 h	Used in imaging to detect the location of damaged heart muscle.
Thulium 170	129 days	Industrial Radiography
Ytterbium 169	32 days	Industrial Radiography
Yttrium 90	2.7 days	Used for therapy in knee joints and liver cancer.
Radioisotopes commonly used in industrial settings		
Caesium 137	30.1 years	Industrial gauges. Well logging / moisture gauges. Transmission Gauges – can penetrate thickness of steel up to 100mm, contents of pipelines, well logging gauges, density gauges, thickness gauge, level gauge, Industrial Radiography.
Californium 252	2.645 years	Industrial gauges. Well logging / moisture gauges.
Cobalt 60	5.27 years	Industrial gauges, level gauge, thickness gauge.
Curium 244	18.1 years	Industrial gauges
Americium 241	432 years	Industrial gauges. Smoke Detectors, Am_{241} & $9Be_{9}$ combined (neutron source) used in portable moisture and density gauges, well logging gauges.
Strontium 90	28.6 years	Backscatter gauges – thickness of plastics, rubber, glass, thin light alloys.
90 Yttrium 90	2.7 days	Backscatter gauges – thickness of plastics, rubber, glass, thin light alloys.
Iridium 192	74 days	Industrial radiography (imaging)
Radium 226	1600 years	Was used some years ago in transmission gauges for density measurements, this isotope is no longer used.
Krypton 82	10.7 years	Industrial gauges. Transmission gauge – thickness of cardboard.
Thallium 204	3.799 years	Thickness gauge for paper & plastic.
Promethium 147	2.63 years	Transmission gauge – density of paper, backscatter gauge – thickness of paper, thin metal coatings.

5.1.2 Waste containing NORM

The waste rock, from certain mining operations, may contain elevated levels of naturally occurring radionuclide material (NORM) and may need to be managed as radioactive waste for radiation protection purposes and safety reasons.

Waste material containing or contaminated with NORM can contain long lived radionuclides at relatively low concentrations that may exceed the levels for exempt waste can be found in the mining and processing of:

- Phosphate minerals.
- Mineral sands.
- Some gold bearing rocks.
- Coal.
- Hydrocarbons.

Waste containing naturally occurring radionuclides can vary considerably in its characteristic and could hence fall into several classes for disposal. Some could have very low activity concentration levels and not require disposal as radioactive waste. Other waste with higher, but limited concentrations could be appropriate for near surface disposal and such waste with higher concentrations were specific radionuclides may have been concentrated may require disposal at greater depth than typical for near surface disposal.

Some NORM contaminated wastes such as those found during the decommissioning of facilities that mine and process radioactive ores, such as pipework, concrete, machinery and PPE, may also require disposal as LLW or ILW.

Some waste, such as some scales arising in the oil and gas industry may have high activity concentration levels. These may necessitate the management of such waste as LLW, or in some cases ILW. Typical industry waste activity concentrations is given in Table 5-2.

Table 5-2 Typical industry wastes activity concentration ranges

Nuclide	Activity concentration (Bq/g)			
	U & Th sands	Radium scale	Radium sludge	Oil & gas+
Pa-231	0.7			
Pb-210	10	0.02-75	0.1-1300	
Po-210	4	0.02-1.5	0.004-160	
Ra-226	10	0.1-15000	0.05-800	1400
Ra-228	70	0.05[!]-2800	0.5-50	1587
Th-227	0.5			
Th-228	70			
Th-230	11			
Th-232	60	0.001-0.002	0.002-0.01	
U-234				
U-235	0.5			
U-238	10	0.001-0.5	0.005-0.01	
[#] It is not foreseen that radium scale & sludge would be disposed of in bulk				

5.2 Waste acceptance procedure

Before a waste can be accepted Tellus must be satisfied that the waste meets the Waste Acceptance Procedures (WAP) and Waste Acceptance Criteria (WAC). The waste acceptance procedure is summarised below and in the flowchart (Figure 5-1).

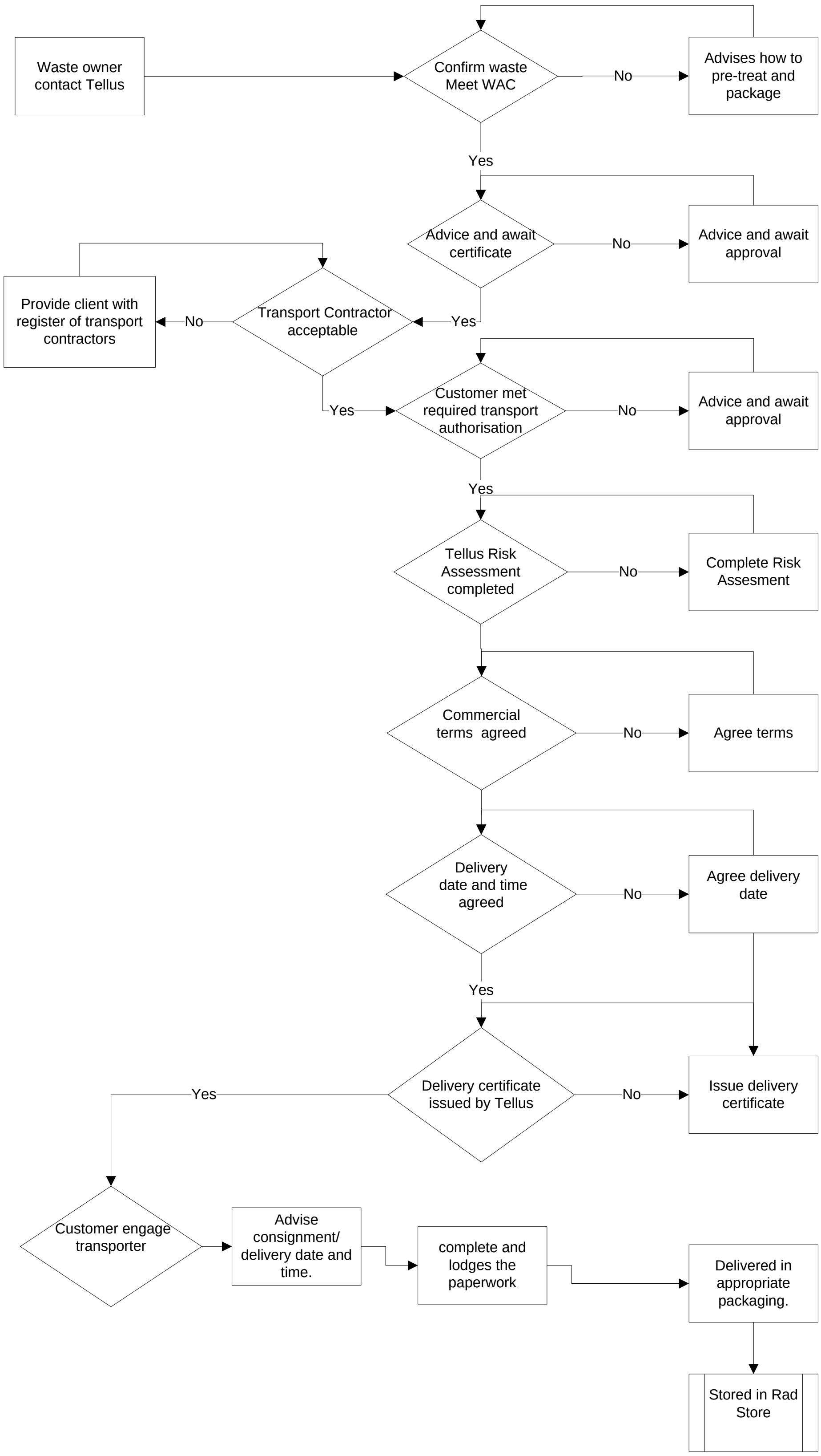
A Customer holding radioactive waste which they want to send to Sandy Ridge contacts Tellus to:

- Advise of the type, form, and quantity of the waste.
- Advise of any requirements for surface storage and potential future recovery.
- Advise of the preferred time and date of delivery.
- Identify any requirements for pre-treatment and packaging.
- Confirm the gate price,
- Confirm any other contractual issues pertaining to storage or permanent isolation certificates.
- Tellus would confirm that the waste meets the WAC, or alternatively advises the Customer how to pre-treat and / or package the waste so that it does meet Tellus' WAC. Sealed sources shall be packaged so that the serial number of the source can be inspected by Tellus upon arrival at the Sandy Ridge site. I.e., encasement in concrete shall not take place prior to an inspection by Tellus.
- If the waste does require pre-treatment or packaging which the Customer cannot carry out themselves, they would be directed to use the services of an established and reputable Waste Management Contractor.

- The customer shall obtain and provide a copy to Tellus of a "Disposal Permit" obtained from the Department of Health, - Radiation Health Western Australia.
- When the waste is in a suitable form and packaging for transport, the Customer advises Tellus of the proposed Transport Contractor. Tellus would maintain a Register of Transport Contractors who has been regularly audited by Tellus for compliance with various levels of hazardous waste transport licencing across all States and Territories of Australia. A new Transport Contractor may be placed on the Register at any time subject to having demonstrated its licences and safe work practices to Tellus. If the customer does not already have established service contracts with an acceptable Transport Contractor, Tellus would be able to recommend one.
- The Customer (or their Transport Contractor) must then obtain and complete all required State, Territory and Federal authorisations and notifications for transport of the waste. These may vary from State to State, and more than one State's authorisation may be required if the transport route passes through more than one State.
- The Customer shall complete and submit a Risk Assessment for the transport of the waste to Tellus. Tellus would provide a standard format risk assessment.
- Only when:
    - the Customer can confirm that the waste does meet Tellus' WAC; and
    - a Disposal Permit has been obtained from Radiation Health (WA); and
    - the proposed Transport Contractor is acceptable to Tellus; and
    - all State and Federal transport requirements have been proven to be met; and
    - a Tellus Risk Assessment has been completed and mitigating actions (if required) are ready to be implemented; and
    - commercial terms have been agreed;

  would a certificate be issued by Tellus to the Customer for the delivery of the waste to the Sandy Ridge site. The date and time of delivery to Sandy Ridge would be mutually agreed at this point.
- The Customer then engages their nominated Transport Contractor to transport the waste to Sandy Ridge.
- The Transport Contractor advises Tellus of when the consignment has departed the Customer's premises, and confirms the expected delivery date and time.
- Upon delivery and inspection at Sandy Ridge, the Transport Contractor and Tellus complete and lodge the paperwork.

Figure 5-1 Radioactive waste acceptance procedure



5.3 Requirements of the waste transport contractor

The following requirements are proposed on transport contractors:

- The Transport Contractor (TC) is licenced to carry the type of waste in each State, which may be transited on the journey between the customer and the Sandy Ridge site. Different States and Territories have differing legislation and requirements pertaining to the transport of hazardous materials and wastes. The TC includes the principal company, all vehicles and operators regardless of whether or not they are independent sub-contractors. If a TC sub-contracts part of the transport service to another party (e.g. railway or shipping service), the principal contractor shall ensure that any subcontractors are identified to Tellus and that they also meet Tellus' TC requirements.
- The TC shall demonstrate to Tellus that it has suitable licences, approvals, permits, management systems and operational practices and they operate in line with the Australia Code for the Transport of Dangerous Goods by Road and Rail to ensure the safe transport of radioactive wastes. The systems and practices shall be appropriate for the type of waste being carried.
- Tellus would maintain a Register of TC and their demonstrated capabilities for various types of waste. A TC would only remain on the Register for a limited period of time before being required to re-qualify and hence be re-instated onto the register.
- Tellus reserves the right to carry out an audit of a TC licences, systems and practices at any time in order for the contractor to remain on Tellus' Register. Failure to comply would result in that TC being removed from the Register, but does not preclude the TC from being re-instated to the Register upon passing of an audit in the future.
- Tellus may use the services of independent auditors or agents to carry out compliance audits of TC.
- Tellus reserves the right to remove a TC from the Register at any time and for any reason.

5.4 Waste handling

Once waste is delivered on site in appropriate transport packaging, it would be treated or stored as required.

5.4.1 Sealed sources

Once delivered to site, sealed sources would be stored in the radiation store building, preferably on pallets in racking. In campaigns, these sources would then be unpacked, inspected and verified. The most used packing configuration is a 60 L drum inside a 200 L drum. Cement slurry would be added to the 60 L to fill all the void spaces and to cover all the items. The cement filled 60 L drums would be placed in the centre of a 200 L drum, which is then filled with concrete. The 200 L drum would be marked with its identification number and labelled.

These drums would be stored until the shaft is prepared for disposal. Drums would then be transferred to the cell, loaded into the shaft and covered with fill/grout.

If any packaging activity is undertaken outside of the radiation compound then the extended area would be designated as a supervised area with appropriate barricades and signage erected. All workers coming into close proximity to the radioactive waste shall wear personal radiation monitors, as supervised by the Responsible Site Office (RSO).

5.4.2 NORM containing pastes / sludges / liquids

Once delivered to site it would be stored in the Radiation Store building or in sea containers on hardstand (location dependent upon activity). In campaigns it would be unpacked, inspected and verified by laboratory testing. It would then be treated with absorbent and pozzolanic materials to form a slurry which would solidify and stabilise the waste. The slurry can then be poured either into drums, moulds, or contained sections of the cell where it would set. If using drums or moulds, the set slurry (solidified) material would be transferred into waste cell.

5.4.3 Contaminated solid materials

Contaminated solid material would be stored in Radiation warehouse building or in sea containers on hardstand (location dependent upon activity) until suitable space is available in cell. In campaigns, depending upon physical size and shape of materials, type and activity of radiation, either;

- Place (compacted) in drums and fill with kaolin or cement grout then disposal in cell or shaft.
- Crush, cut or otherwise (if needed) to remove void space in object and fill remaining voids in object with cement grout or kaolin solids and place in cell or shaft.
- If necessary, place entire sea-container in cell, cut holes in top and fill all void space with cement grout.

5.4.4 Contaminated soil or sands (bulk)

Depending on the volume and physical characteristics of material it would be delivered to site in either bulka bags, shipping containers or as wetted down sand. Practical transport would be arranged to coincide with a disposal campaign; If not possible (as might be the case after an emergency clean-up operation) the material would be stored the radiation store; If too bulky separate demarcated stockpile areas would be set up. Dust control would be applied to material to prevent any spread of contamination and the area would be screened after removal of the stockpile to ensure the contamination levels are back to background radiation. The bulk material can be disposed of directly in the cell, diluted or mixed with other material, or set in concrete if required.

6 CONTROLLING RADIATION EXPOSURE

6.1 Introduction

When examining options in an endeavour to rectify an undesirable situation, Tellus would adopt the following hierarchy of control measures:

- Eliminate the hazard.
- Substitute a work process for one in which exposure levels are decreased.
- Engineering control to prevent or reduce contact between the hazard and people (e.g. shielding, ventilation, isolation).
- Apply administrative controls such as placarding, time restrictions, work procedures and training.
- Personal Protective Equipment. Tellus considers the use of personal protective equipment such as respirators, acceptable whilst engineering controls are being developed and implemented, or where such controls are not practicable.

In eliminating and reducing hazards, Tellus believes that 'due regards' should be given to best practicable technology. This would take into account:

- Prevailing circumstances and conditions.
- Current state of technological knowledge.
- Safe working conditions and whether these are being compromised by introducing the control.
- Social and economic factors and consequences.

6.2 Engineering design controls

During the disposal operations the exposure to external γ-radiation is kept to a reasonable minimum by:

- The cell design.
- Radiation warehouse design.
- Ventilation.
- Packaging.

The disposal cell is designed in such a manner that radioactive waste can be placed after the other waste. The most radioactive waste can also be placed at the bottom of the shaft to reduce exposure risk. This reduces the exposure time; increases the distance between radioactive waste and workers and provides shielding between waste and potential receptors.

Potential exposure to γ-radiation from radiation gauges is minimised by setting those sources in concrete inside steel drums. This provides shielding, additional security of sources and reduces risk of exposure.

The radiation warehouse is designed and would be built to provide shielding and reduce risk of exposure. It would also be demarcated and access controlled to prevent unauthorised entry and exposure. It would also be built to ensure security sources kept.

If NORM wastes are stored with a risk of Radon gas build-up, ventilation systems would be used to ensure the risk is reduced to ALARA.

6.3 Dust control system

If there are stockpiles stored on site and material can be spread by wind the following practices are implemented:

- Ad Hoc stockpile are would be designed with a concrete slab and bunding. It can also be closed off with tarp or mesh material to ensure no generation of dust.
- Maintaining a minimum open air stock level to minimise drying and dust generation.
- A watering system and wind breaks to prevent the generation of dust.
- Shade cloth mesh barriers can be used in areas best suited to their application to prevent the generation of dust ad form wind breaks if needed.
- A dust suppression agent can be applied to non-active stockpiles to prevent dust emissions leaving the premises during periods of high winds; and
- A Comprehensive dust monitoring program, consisting of both personal and environmental dust monitoring, are in place to monitor and report on the efficiency of the existing control measures.

6.4 Contamination control

The site boundary is screened at least annually to confirm the efficiency of controls in place to prevent contamination of neighbouring properties.

All equipment that may be contaminated with radioactive material is screened to ensure they are within the release limits. Surface radiation contamination on plant and equipment must be less than 0.4 Bq/cm^2 averaged over 300 cm^2, otherwise plant and equipment is not released from site.

6.5 Institutional Control

6.5.1 Responsibilities of key personnel

The duties of key personnel for the implementation and maintenance of the RMP are detailed in Table 6-1.

Table 6-1 Duties of key personnel

Item	Action	Responsible person
1	Provide advice to the management on the implementation of the RMP.	Radiation Safety Officer
2	Provide advice in matters in relation to radiation protection of employees, public and environment.	Radiation Safety Officer
3	Accountability of all radiation sources on site.	Radiation Safety Officer
4	Monitoring of radiation hazards in accordance with the Standard job procedures.	Monitoring technicians/ Radiation Safety Officer
5	Ensuring that the nominated radiation monitoring is carried out and that the results are reported to appropriate employees, management and government departments.	Radiation Safety Officer
6	Following the nominated safe working practices policies, procedures and appropriate requirements for radiation monitoring.	All employees
7	Ensuring all incidents is immediately reported to the responsible person.	All employees
8	Authorising all Company policies, including those relating to radiation protection.	Site Manager
9	Implementation of the Company's policy on radiation safety.	Area Co-ordinators and Supervisors

6.5.2 Areas classification and work rules

To ensure ALARA principles are maintained, classification of areas is done based on the potential annual radiation exposure in excess of the natural background and the following work rules apply to those areas:

- **"Radiation supervised area"**: an area to which access by members of the public should be minimised and restricted.
  - General awareness of elevated radiation levels in the area is required both for employees and for visitors. Visitors to the site must be accompanied at all times.
- **"Radiation Controlled area"**: an area to which access by employees should be limited or minimised;
  - Only employees who have attended radiation safety training are allowed to work in these areas. Employees who have not attended this training are allowed to work only in exceptional circumstances.
- **"Radiation restricted area"** is an area where the potential for the radiation exposure of employees is above 75% of the annual dose limit.

- o Only employees who have attended radiation safety training are allowed to work in these areas and wearing of a personal radiation monitor (a thermoluminescent dosimeter (TLD) badge or an electronic dosimeter) is mandatory.
- o Visitors or employees who have not attended radiation safety training are not permitted to enter these areas under any circumstances except in emergency situations.

6.5.3 Emergency planning

Emergency procedures will be developed to prepare for accidental spillage while transporting sources, fires and other relevant emergency situations.

6.5.4 Personal protective equipment

Respiratory protective devices would be permanently available in the workplace. Instruction, training, proper maintenance and efficient use of the respirators would be carried out on an ongoing basis throughout the year so as to ensure the coverage of all new employees.

6.5.5 Personal hygiene rules

All employees are made aware during site induction of the risk of radiation exposure. They are made aware of the increased risk to radiation exposure if personal hygiene is not followed before eating, drinking or smoking.

Ablutions facilities are made available on site to enable employees to follow good personal hygiene practices.

6.5.6 Job rotation

Designated employees dosage are monitored and calculated quarterly while pregnant employees dosage are calculated weekly. If an employee reaches 50 % of the annual exposure dose limitation, they would be removed to a non-designated area to ensure they are not being overexposed. Monitoring of these employees would continue to ensure no overexposure to radiation. If 75 % of the annual dose limitation is reached the employee would be sent on leave or moved to activities where there is low radiation exposure levels to ensure they are not over exposed. The levels by which jobs would be rotated are given in Table 6-2.

Table 6-2 Job rotation levels

Exposure level	Pregnant employee (mSv)	Designated employee (mSv)	Action
50% of dose limitation	0.5	10	Rotate employee to work in non-designated or lower radiation area
75% of dose limitation	0.75	15	Employee to be sent on leave to prevent over exposure

6.5.7 Management of pregnant employees dose

During general site induction, it would be made known to employees that they should report to the Human Resource Department or their supervisor, as soon as practical if they become pregnant during the course of their employment. Once an employee has reported her pregnancy, the employee is issued with a personal dosimeter (Canary), and is provided with an Excel spreadsheet to record her daily dose received. She would also be trained in filling out the spreadsheet.

The spreadsheet will calculate the dose above background received the accumulated dose to date and give a predicted dose based on the dose received and the pregnancy time remaining.

An employee's dose would be monitored throughout the pregnancy and she would be relocated to a less radioactive area if needed to ensure her dose received would not exceed 1 mSv over the pregnancy period.

7 COMPLIANCE WITH LIMITS

The majority of risks associated with radiation are known and have been quantified. The objective of radiation protection is to limit the exposure to radiation by the application of comprehensive programs of measurements of all significant radiation sources.

Where it is expected that a worker would be exposed to radiation as a result of their employment, they must not exceed certain prescribed dose limits. In Australia, these dose limits are prescribed in the *Recommendations for Limiting Exposure to Ionizing Radiation* (1995) and *National Standard for Limiting Occupational Exposure to Ionizing Radiation* (2002), Radiation Protection Series No. 1 which reflects international best practice in radiation protection.

A dose constraint is an upper value on the annual dose that members of the public or member of the workforce may receive from a planned operation or a single source. A dose constraint would allow for exposures from other sources without the annual limit being exceeded.

The dose limit for members of the public from all sources is an effective dose of 1 mSv in a year, and this or its risk equivalent should be considered as criteria not to be exceeded in the future. The ICRP and IAEA suggest that, for the control of public exposure, an appropriate value for the dose constraint is 0.3 mSv in a year (mSv/y) exclusive of natural background levels.

This dose constraint should take into account multiple pathways of exposure as members of the public could receive exposure from a number of sources. To comply with the above limit, a facility such as a radioactive waste disposal facility (which constitutes a single source) must be designed so that the estimated average dose to the relevant critical groups of members of the public, who may be exposed as a result of the facility and its operation, satisfies a dose constraint of not more than 0.3 mSv per year exclusive of background.

The current worker limit of radiation exposure is 20 millisieverts (mSv) per year averaged over 5 years, and not more than 50 mSv received in any one year. This dose limit only applies to radiation exposure received occupationally, and does not include exposures from natural background radiation or medical doses. To Ensure compliance to this level the facility would follow a dose constraint level 0f 5 mSv/y

To ensure compliance with these limits action levels are established and given in Table 7-1. If exceeded, formal investigation of the excursion is required.

Table 7-1 Investigation levels

Radiation parameter	Guideline level	Comment
Area Gamma dose rate		
Site boundary	More than 0.11 µGy/hr above background	
Supervised area	More than 0.50 µGy/hr above background	
Controlled area	More than 2.50 µGy/hr above background	
Restricted	More than 7.50 µGy/hr above background	
Personal external dose		
Designated worker	>2. mSv in a quarter	Assessed from TLD/ personal dosimeter
Non-designated worker	>0.5 mSv in a quarter	Assessed from TLD/ personal dosimeter
Personal internal dose		
Designated worker	>0.5 mSv in a quarter	Assessed from air sampling
Airborne radioactivity		
Total alpha activity on the personal air sample	>4 Bq/m^3 for shift sample	Four times derived air concentration limit 0.5 mSv.
Total alpha activity on the personal air sample	4 consecutive samples >1 Bq/m^3	Indicates potential for significant exposure.
Total alpha activity	>Mean + 3 std deviations	Work category mean.
Total Alpha activity on environmental air sample	>1 mBq/m^3 on high volume air sampler	100 µSv/year to a member of public continuously exposed. (>10 x background levels.
Airborne dust		
Inhalable dust on personal air sample	>10 mg/m^3 dust concentration	Statutory limit for inhalable (8 hour shifts).
Respirable dust on personal air sample	>3 mg/m^3	3 mg/m^3 (8 hour shifts).
Radon / Thoron in air		
Radon in air _ workplaces	>1000 Bq/m^3	Assessed from track etch -long term average.
Surface contamination		
Low toxicity alpha emitters (U238, Th232, Th228, Th230) on a surface	>0.4 Bq/cm^2	Averaged over 300 cm^2. Non-fixed - can be removed from surface during handling.
Other alpha emitters (Ra226, Ra224, Po210) on a surface	>0.04 Bq/cm2	Averaged over 300 cm2. Non-fixed - can be removed from surface during handling.

8 WORKER EXPOSURE AND CONTROLS

8.1 Transport

Workers involved in the transport of radioactive material to site could potentially be exposed to external gamma radiation from the waste package, inhalation of suspended dust (α- radiation) and inhalation of radon and decay products. Transport would be arranged by the customer and all exposure assessments should be addressed in the customers' transport management plan and emergency procedures. The Proponent requires that all packages that arrive on site must be transported in accordance with requirements of the Australian Code of Practice for the Safe Transport of Radioactive Material that adopts International Atomic Energy Agency (IAEA) Transport Safety Regulations.

8.2 Front gate

The truck transporting shipping containers would enter the facility and be weighed on the weighbridge and the driver would then proceed to the front gate office. The operator at the front gate would confirm:

- No visible damage to the shipping container(s).
- No evidence of material leaking from the shipping container(s).
- Radiation levels on the surface of the shipping container is in line with transport requirements.
- Various points of the truck would be inspected.

If the truck does not meet Tellus' required standards, it would be quarantined in a holding bay, away from areas in which people are working, and Tellus would liaise with the waste customer regarding the discrepancy. Once confirmed that the shipping container meets Tellus' transport standards, it would be moved to the hardstand.

Operators working at the front gate could potentially be exposed to external gamma radiation from the waste package, inhalation of suspended dust (α- radiation) and inhalation of radon and decay products.

Controls that would be implemented to ensure workers are not exposed to levels above the dose constraints include:

- Screening of waste packages on arrival to ensure the radiation levels (alpha beta and gamma) is within acceptable and safe levels.
- Wearing of electronic dosimeters to determine exposure levels.
- Ensuring packages are not damaged on arrival and adhere to the transport requirements.
- Dust controls if bulk material are handled.

- PPE if required.

8.3 Hardstand

Trucks would park temporarily on the hardstand whilst the shipping container is transferred to the hardstand. The shipping container remains closed. An external audit is conducted to ensure the container is not damaged or leaking. If it is found to be leaking Tellus would move it directly into the Waste Inspection Area to conduct an internal audit and remove the leaking/damaged waste packages. Clean-up of leaked material on the hardstand would be in accordance with SROP-06 Spill Clean-up Procedure.

Otherwise the shipping container would remain on the hardstand until the operators of the Waste Inspection Area are ready to receive it.

Workers involved in the inspection and clean up could potentially be exposed to external gamma radiation from the waste package, inhalation of suspended dust (α- radiation) and inhalation of radon and decay products.

Controls that can be implemented to ensure workers are not exposed to levels above the dose constraints include:

- Screening of waste packages to ensure correct time limits is placed on work (reducing exposure time by rotating workers etc.)
- Wearing of electronic dosimeters to determine exposure levels
- Limiting the time workers work near waste (determined by dose rate of waste package) to ensure they do not exceed dose constrains.
- Using remote controlled equipment if required.
- Ensuring packages are not damaged on arrival.
- Dust controls if bulk material are handled.
- Ensuring proper ventilation to prevent built up of radon gas
- PPE if required.

8.4 Waste inspection area

The shipping container would be lifted onto the Waste Inspection Area dock and one end of the container opened to allow access for the internal audit. The audit would be conducted in accordance with SROP-07 Internal Shipping Container Audit.

A number of waste packages would be removed from the shipping container and placed on the floor of the Waste Inspection Area. Radiation of the waste packages would be checked in accordance with SROP–04 Radiation Monitoring and would confirm if the emissions match those expected based on the customer's waste preform. If the radioactivity recorded is higher than expected based on the information provided by the waste customer, the following actions would occur:

- The radiation meter would be re-calibrated in accordance with manufacturer's specifications.
- The radioactivity of the waste package(s) would be recorded again.
- If the recording is still higher than expected, but below the radiation levels are as per the transport code and labelling (no greater than: 5 µSv/h for a Category I-WHITE package; 500 µSv/h for a Category II-YELLOW package; or for a Category III-YELLOW package up to 2000 µSv/h (or 10 000 µSv/h if transported under exclusive use)and that non-fixed external contamination does not exceed 4 Bq/cm2.) the waste packages would be moved to the Radioactive Waste Warehouse. Tellus would liaise with the waste customer to confirm the reason for the discrepancy and if satisfactory, an Acceptance Certificate would be issued.
- If the recording is still higher than expected, and above the radiation levels are as per the transport code and labelling, further testing, options and cost involved would be discussed with the waste customer. If unable to treat and reduce the radioactivity to within acceptable levels, Tellus would be unable to place the waste package in the cell (as this would contravene approvals issued for the site) and the waste customer would be contacted to organise removal of the waste package from the site. The waste packages may be temporarily stored in the Radioactive Waste Warehouse until this is organised.

Following checking of the packages for radioactivity, sampling of these waste packages would occur in accordance with SROP-08 Sampling of Wastes, and each sample would undergo checks against the customer's documentation and laboratory testing.

The waste package would be audited against the customer's waste proforma to confirm the volume and type of waste delivered is as described in the customer's documentation. The outcome of the review of documentation would be:

- If the documentation is incomplete or does not match the waste that has arrived, the package is replaced into the shipping container, the container is closed, and is moved back to a section of the hardstand pending liaison with the waste customer.
- If documentation is complete, the waste packages would be inspected for damage and leaks. If the packaging is damaged significantly the pallet would be held in a safe and secure manner (in accordance with SROP–09 Damaged or Leaking Waste Package Procedure) whilst a solution is agreed to with the waste customer.

Tellus would make safe any damaged or leaking waste package as soon as possible to minimise worker exposure to the waste

Following internal audit of the shipping container, all waste packages examined would be repacked into the container. The shipping container would either be:

- Transferred directly to the cell for disposal.

- sent to the hardstand to await placement as per the Cell Schedule (described further below).
- Sent to the Radioactive Waste Warehouse for temporary storage.

Workers involved in the inspection of radioactive waste can be exposed to external gamma radiation from the waste package, Inhalation of suspended dust (α- radiation) and Inhalation of radon and decay products.

Controls that would be implemented to ensure workers are not exposed to levels above the dose constraints include screening of waste packages on arrival to ensure the radiation levels (alpha beta and gamma) is within acceptable (as specified in the transport code) and safe levels, wearing of electronic dosimeters to determine exposure levels, dust controls if bulk material are handled and PPE if required.

8.5 Lab

Composite and random samples of the newly arrived waste packages would be collected and tested in the onsite laboratory. Testing would ensure the chemicals sent are as per the waste customer's documentation.

The onsite laboratory would be accredited by the National Association of Testing Authorities (NATA) for the analysis to be performed. Chemical analysis would be performed in accordance with the laboratory methods accredited by NATA. The laboratory would produce sample results which would be stored in the Tellus Electronic Tracking System (TETS) alongside the waste customer's proforma and NEPM documentation.

Once the sample results match the customer's documentation, the remnants of the sample, the previously removed waste packages, equipment contaminated by the sample and the lab analyst's personal protective equipment (PPE) would be repacked into the shipping container and the container closed. The shipping container is transferred back to the hardstand. The shipping container remains on the hardstand until it is scheduled to be moved into the waste cell.

Controls that would be implemented to ensure workers are not exposed to levels above the dose constraints include screening of waste packages on arrival to ensure the radiation levels (alpha beta and gamma) is within acceptable (as specified in the transport code) and safe levels, wearing of electronic dosimeters to determine exposure levels and engineering designed controls I lab.

8.6 Radioactive waste warehouse

The Radioactive waste warehouse is designed to ensure that the dose rate outside of the building do not exceed 10µGy/hr. The warehouse would be demarcated as a designated area and access to the warehouse and time spend in it would be controlled.

8.7 Pre-treatment / packaging of wastes

Tellus may accept some wastes at the facility which are flammable, explosive, corrosive, biodegradable or reactive which would require pre-treatment or conditioning before being placed in the disposal cell to ensure that they do not compromise cell integrity. Possible pre-treatment processes may include one or more of the following:

- Crushing and/or screening to ensure that the particle sizes of materials would not result in excessive voids being created (e.g. for pot liner materials).
- Solidification and stabilisation using pozzolanic cement, fly-ash or kaolinitic materials.
- Centrifugation or filtering to remove excess moisture.
- Evaporation and biological conditioning.

Workers involved in the packaging of radioactive waste for disposal (cementing and concreting) can be exposed to external gamma radiation from the waste package, Inhalation of suspended dust (α-radiation) and Inhalation of radon and decay products.

Controls include packaging within a well ventilated designated area, all workers coming into close proximity to the radioactive waste shall wear personal radiation monitors, limiting the time workers spend packaging, increasing the distance between workers packaging the waste and sources, and shielding.

8.8 Transfer of waste into cell

Workers involved in the unloading and burial of radioactive waste may be exposed to low levels of external gamma radiation from the waste package, Inhalation of suspended dust (α- radiation) and Inhalation of radon and decay products. The waste at this stage is packaged and would be lowered into the shafts by mobile equipment. Workers protection include shielding (provided by the waste packaging and mobile equipment), increase in distance from sources by using mobile equipment and scheduling of waste placement to ensure minimum time is spend near radioactive waste.

9 EMPLOYEE TRAINING

All personnel and contractors working on the site would undergo a standard induction that would include background and project specific information on radiological conditions and hazards.

The radiological induction would be provided through a power point presentation to be given by the RSO and an information booklet.

Relevant personnel would be trained in the use of all radiological monitoring equipment prior to commencement of the project.

This induction and training would be backed up by the on-site presence of the Radiation Safety Officer and off site access (via telephone and email) to radiological expertise through Hygiea Consulting.

10 RADIATION MONITORING PROGRAMMES

The radiation monitoring programs would follow a conventional format for each of the types of hazards described.

The aim of the monitoring programme is to:

- Demonstrate regulatory compliance.
- Assessment of the efficiency of work practices and engineering controls in preventing and limiting employee and public exposure to radiation.
- Provide data to enable knowledgeable radiation protection decision-making.

The general procedures are:

- To conduct area gamma and airborne activity surveys to define general baseline radiation levels before the project is started.
- To conduct area gamma and airborne activity surveys before finalising the preliminary earthworks phase to confirm that sufficient material has been removed and to confirm no spread of contamination to neighbouring areas
- To comprehensively monitor people who work in the areas by:
  - Individual gamma monitoring to determine external γ-radiation.
  - Random personal dust samling to determine airborne radioactivity.
- To conduct assessments of doses received by employees and the critical group.
- To ensure action levels are not exceeded.
- To investigate and correct any situation that results in an action level being exceeded.
- To adopt practical preventive measures at all times to limit the exposure of all persons.

The purpose of the Environmental program is to ensure that radiological impact to the local environment and to members of the public is minimal. This program is usually accomplished by area monitoring (dust and water monitoring, and area γ-surveys).

10.1 Environmental monitoring programme

The environmental monitoring program is adapted based on on-going interpretation of results and risk assessments before disposal and waste acceptance. The following environmental radiation monitoring programme (Table 10-1**Error! Reference source not found.**) would be followed as a minimum to ensure that the operations have no detrimental effect on the environment.

Table 10-1 Environmental monitoring schedule summary

Monitoring type	Type of monitoring	Type of radiation	Pre-operational	Baseline (operational)
Dust Monitoring	Environmental high volume dust samples	LLA	1/year from 6 representative locations.	2/year from representative locations.
Radon	Track etch	RnDP	1/ year from 3 locations.	2/year for first 3 years of operation – then as per determined risk.
Area γ-Monitoring	Pre disposal background gamma levels	γ-survey	Pre clearance survey before cell is mined.	Pre disposal (mined out pit), after disposal and after final capping.
	Boundary gamma surveys	γ-survey	Once off.	Annually.
	Equipment contamination clearance	α, β, γ-survey		As required before equipment that might be contaminated leave site.
Waste storage	Radiation store	γ-survey		Quarterly.
	Stockpiles	γ-survey		2/year.

10.1.1 Dust monitoring

Samples are deposited upon a pre-weighed (25.5 cm x 20.5 cm) glass-fibre filter paper with an effective sampling area of 382.5 cm^2 (22.5 cm x 17.0 cm). Upon completion of sampling, the filter paper is re-weighed to determine the mass of dust collected. The sub-samples are stored for a period of not less than seven days to allow short lived radioactive products to decay, and are then presented to the α-spectrometer to determine the long-lived α-emitting activity. The mean α-activity from the sub-samples is integrated over the total active area to determine total collected long-lived α-activity.

10.1.2 Environmental area γ- monitoring program

Environmental area γ- monitoring program would consist of:

- Site boundary monitoring surveys.
- γ- monitoring to determine Background levels.
- Clearance survey.

The environmental gamma survey would be done at a height of 1 metre from the ground. Keeping the monitor and audio indicator in the on position allow for the identification and monitoring of smaller areas with elevated gamma radiation levels. A grid of approximately 15 m x15 m is recommended.

- All monitoring locations are recorded using a Global Positioning System (GPS) receiver.
- Area γ- monitoring of the site boundary would be undertaken as part of the pre operational and operational baseline program. The monitoring locations would be recorded with the GPS coordinates and compared to the pre-project monitoring results.
- A survey would be undertaken once mining has been completed and before disposal to confirm the background levels in the pit. The survey results with the GPS coordinates would be record
- A clearance survey of each pit would be undertaken after completion of earthworks and capping to confirm area above pit is at background levels. Results and GPS coordinates would be recorded.

10.2 Occupational monitoring program

The purpose of the occupational monitoring program is to ensure that radiation exposures of the workforce remain below the statutory annual limit (20 mSv) and ALARA. Occupational radiation monitoring is carried out on a cross section of the employees. Results of area surveys and time and motion studies are also used to estimate potential doses for employees. The personal monitoring to be conducted would include:

- Personal dust samplers and analysis for gross α activity.

- Personal γ- monitoring with personal electronic dosimeters (Canary).
- Work Area γ- monitoring to demarcate areas based on exposure risk.

10.2.1 Personal dust monitoring

Personal dust sampling would be conducted in accordance to AS 3640:2004. Workplace atmospheres -Method for sampling and gravimetric determination of inhalable dust, 2004. Samples would be analysed for LLA. ICRP-66 recommends that a default AMAD of 5 µm is used for occupational exposures whilst for environmental exposures the default AMAD is taken to be 1 µm.

Sampling sizes for the baseline program would be in accordance with NIOSH Occupational exposure sampling strategy manual to ensure that there is a 90% confidence that at least one individual from the highest 10% exposure group is contained in the sample.

10.2.2 Personal γ-Radiation monitoring

Personal γ monitoring would be conducted to confirm the individual dose is kept below the action levels. This would be done with personal electronic dosimeters or Thermoluminescent Dosimeter (TLD) badges.

10.2.3 Area γ- Monitoring

Work areas would be classified based on the potential annual radiation exposure in excess of the natural background and would be demarcated accordingly.

The average level of natural background gamma radiation would be determined in the pre operational surveys.

11 PERIODIC ASSESSMENT AND REVIEW

This Radiation Management Plan would be reviewed on an annual basis. The review would be documented and involve stakeholders where appropriate. In addition to an annual review the frequency and scope of various monitoring programs would be periodically reviewed. This would ensure that the various monitoring programs are implemented in a way that would allow the timely identification and rectification of any potentially unforeseen circumstances or areas of concern.

12 SUMMARY AND CONCLUSION

Tellus Holdings Ltd (Tellus), an infrastructure project development company, is proposing to develop the Sandy Ridge Project located approximately 75 kilometres (km) North East of Koolyanobbing, in the Shire of Coolgardie, within the Goldfields Region of Western Australia.

The Sandy Ridge proposal is a kaolin open cut mine and use the mine voids for the secure storage and permanent isolation over geological time of hazardous, intractable and low to intermediate level radioactive waste in an arid environment, near surface, geological repository using best practice storage and isolation safety case. The location of the Sandy Ridge Project has been specifically chosen to meet the requirements of International and National codes relating to the siting of a near surface geological repository.

Intractable wastes do not have commercially viable recycling, reuse or disposal options; and include wastes that need time to breakdown; and chemical wastes that are not readily destroyed. These wastes need long-term management. The Facility provides a location where intractable wastes can be permanently isolated to protect the community and the environment. The type of industrial materials waste to be stored or permanently isolated are intractable and hazardous materials generated in the; mining, oil and gas, heavy industry, agricultural and government (emergency service) sectors.

Waste acceptance criteria (WAC) developed for this facility is described in the waste acceptance criteria (document reference: TCO-5-05). The radionuclide concentration limits is set taking into account the actual siting, design and planning of the facility (e.g. Natural geological barrier, arid climate, remoteness, engineered multi layered shielding and barriers, duration of institutional control, site specific management plans and operating procedures) and exposure dose constrains to ensure no person is exposed above the dose limit (as defined in Schedule I of the Radiation Safety (General) Regulations).

During the feasibility stage of the project, considerations were given to engineering best practice as well as socio economic factors to determine the most suitable design that would meet the safety requirements at an acceptable cost. The current proposal is open cut pit/cell with in-cell vertical shaft disposal of radioactive wastes.

All wastes would be securely isolated in the safety of the natural geological barriers formed by the extensive kaolin bed and the overlying geological units. Cells would be filled in layers with multiple sections in each layer containing wastes of similar characteristics. All space between waste packages would be backfilled and compacted to minimise air or void space that may result in settlement. Each layer would be compacted, until approximately 7m below the ground surface, where a thick capping layer of low permeability clay would be installed to prevent water ingress into the cell.

Following these steps, more compacted backfill and a clay domed cap would be situated on the top of the cell, to shed any landing rainfall. During the waste disposal process a roof canopy is positioned over the cell to exclude rainfall prior to the capping layer being installed. There may be instances (for non-soluble waste types) where a cell may be filled with waste without a roof canopy. In addition, any potential stormwater surface flows would be diverted away from the cells by bund walls or levee banks.

The facility security design would be in accordance with ARPANSA RPS 11 in order to decrease the likelihood of the unauthorised access by persons with malicious intent.

It can be concluded on the basis of the characteristics described above and the initial dose assessments, that there is little credible risk to human health or the environment from suitably conditioned and packaged hazardous or intractable wastes that might be stored and isolated in appropriately designed disposal cell at Sandy Ridge.

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Radiation Assessments

TELLUS

RADIOLOGICAL RISK ASSESSMENT : FAUNA & FLORA
SANDY RIDGE FACILITY

Company Name: TELLUS HOLDING
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EXECUTIVE SUMMARY

Tellus proposes to construct and operate a dual Kaolin (Clay) mine and waste facility, accepting Class IV (Secure Landfill) and Class V (Intractable Landfill) waste.

The type of industrial materials to be accepted at the facility are intractable and hazardous materials generated in the mining, oil and gas, heavy industry, agricultural and government (emergency service) sectors.

As well as ensuring humans are adequately protected from exposure to radiation and radioactive material handled, stored and disposed at the Sandy Ridge near surface geological storage and isolation facility (the Facility), there is a need to ensure the environment, as a whole, is adequately protected.

An assessment has been undertaken, with the intention of estimating the radiological effects that waste materials could have on the environment. This includes all pathways of exposure, both during the period of operation and closure, with the view to demonstrate that potential radiological impacts are at an acceptable level of risk and manageable to safeguard fauna and flora.

This assessment was undertaken using the Environmental Risk from Ionising Contaminants Assessment (ERICA) software tool. In ERICA, the reference organisms are characterised by their dimensions, the concentration of radionuclides that they exhibit relative to the environmental media with which they are associated and the fraction of the time (occupancy) that they are present within, or at the surface of, the various environmental media. With this information, dose conversion factors can be used to convert concentrations in organisms into whole-body dose rates, which are then compared to threshold dose rates (dose constrains) (e.g. 10 µGy/h) for various broad categories of organisms to which there are not expected to be significant population effects.

Four exposure scenarios were modelled using ERICA Tier 2 assessments:

- Scenario 1 – exposure of fauna and flora present in the area surrounding the radioactive waste warehouse.
- Scenario 2 – exposure to windblown material originating from operational stockpiles e.g. plant tails; ore, sand, laterite and silcrete stockpiles.
- Scenario 3 – exposure to windblown material originating from adhoc stockpiles e.g. low level radioactive materials received as bulk or from emergency clean-up operations.
- Scenario 4 – exposure post closure, with capping material and rehabilitation of the GSIF established as well as for the duration of the institutional control period.

The conclusions of the assessment are as follows:

From the Scenario 3 modelling, it was indicated that exposure to waste materials at full-time occupancy (with no controls in place) could result in radiological impacts too high for adequate protection of flora and fauna, it is imperative to ensure that stockpiled radioactive bulk materials are sufficiently contained to prevent windblown (or other) dispersal to the surrounding environment. It is also recommended to establish control measures preventing fauna species access to stockpiled bulk materials during the operational phase of the project. The controls that will be implemented are discussed in section 9.2 of the radiation management plan and include a designated stockpile area with concrete slab and bunded walls, closing stockpile with tarp material, dust suppression agents and a monitoring program to confirm efficiency of controls implemented. With these controls in place and operating according to design the exposure risk should be sufficiently managed.

From the Scenario 1 modelling (exposure of fauna and flora present in the area surrounding the radioactive waste warehouse), and under the condition that the Sandy Ridge facility will be designed and constructed such that dose rates for all organisms present outside the warehouse are below the threshold dose rate of 10 μGy/h, no risk to any biota is foreseen from stored materials.

Upon closure, with a minimum capping of 7 meters, and for the duration of the institutional control period, no risk to non-human biota is foreseen, as modelled dose rates for all organisms are below the threshold dose rate of 10 μGy/h. External gamma dose rate on surface post closure (minimum cover of 7 m) would be negligible, even if all radioactive waste (2,500,000 tonnes) would be high activity concentration radium scales at an activity concentration of 17800 Bq/g radium (Ra-226 and Ra-228 combined).

1 SCOPE

Tellus proposes to construct and operate a dual kaolin (clay) mine and waste facility, accepting Class IV (Secure Landfill) and Class V (Intractable Landfill) wastes.

An assessment has been undertaken, with the intention of estimating the potential radiological effects that waste materials stored and disposed of at the Sandy Ridge facility could have on the flora and fauna. The assessment included all pathways of exposure during the periods of operation and closure, with the view to demonstrate that the radiological impacts are at an acceptable level of risk and manageable to safeguard fauna and flora.

2 INTRODUCTION

Tellus is planning to develop the Sandy Ridge Project (the Proposal). The Proposal is comprised of two main business components, mining of kaolin clay for export and storage and permanent isolation (disposal) of hazardous and intractable waste in mine voids.

The proposed commodity business involves mining kaolin mostly in an open cut methodology, processing on site and then exporting the kaolin via Fremantle Port to Asia where it will be used in various industrial sectors (e.g. paper, ceramics, fiberglass and paint). Kaolinite is a clay mineral also known as ‘Kaolin clay’, with the chemical composition $Al_2Si_2O_5(OH)_4$.

The waste aspect of the Proposal involves disposing of up to 100,000 tpa of intractable, hazardous and low level radioactive wastes in the mine voids (herein referred to as ‘cells’) over a 25 year period (i.e. 2,500,000 tonnes in total). Wastes would be accepted from across Australia.

Cells would be filled in layers with multiple sections in each layer. Each layer would be divided into sections containing wastes of similar characteristics. Each section will be backfilled, compacted and all air pockets/voids excluded. Each layer will be compacted, until approximately 7m below the ground surface, where a thick capping layer of low permeability clay will be installed to prevent water ingress into the cell. Following this, more backfilling and a clay domed cap would be situated on the top of the cell, to shed any landing rainfall. During the waste disposal process, a roof canopy is positioned over the cell to exclude rainfall prior to the thick capping layer being installed.

Waste acceptance criteria (WAC) developed for this facility is described in the waste acceptance criteria (document reference: TCO-5-05). The radionuclide concentration limits is set taking into account the actual siting, design and planning of the facility (e.g. Natural geological barrier, arid climate, remoteness, engineered multi layered shielding and barriers, duration of institutional control, site specific management plans and operating procedures) and exposure dose constrains to ensure no person is exposed above the dose limit (as defined in Schedule I of the

Radiation Safety (General) Regulations). These radioactive wastes are generally generated by medical research and industry, operation of research facilities (e.g. laboratory coats, overshoes, gloves), Naturally Occurring Radioactive Materials (NORMs), NORMs occurring on pipework and scale from industry, oil spills containing NORMs and orphan sources (i.e. gauges and instrumentation). Wastes which will not be disposed of into cells include: infectious materials, nuclear material, uncertified waste, putrescible waste and gases.

Tellus operations are underpinned by utilising a combination of engineered and natural barriers, known as a multi barrier system, which provides long term containment and isolation of the waste.

After the placement of waste in the cell has been completed, the following protection measures will be implemented:

- An all-weather cover will be maintained over the cell until it is backfilled and capped to allow for protection from all weather conditions, without the possibility of creating leachates or contaminated surface water.
- Any airspace surrounding the placed waste will be backfilled with kaolin processing plant waste product (low value kaolin and quartz sand) to fill all void space and provide stability.
- The cell will then be backfilled with compacted clay, silcrete, laterite and yellow sand.
- The surface of the cell will be covered with a domed clay cap to exclude rainfall.

After a period of subsidence monitoring to confirm the stability and integrity of the clay capping, topsoil will be placed over the cap and the area re-vegetated with species of local provenance. Local species would be selected based on their root system penetration (depth), ensuring that the capping design is not compromised.

Tellus will monitor and manage the site for an extended period following closure before returning ownership to State, a period termed institutional control. Further information on management of the Facility is provided in the Waste Facility Decommissioning and Closure Plan.

The institutional control period (ICP) will ensure the wastes stored and disposed of in the geological repository are undisturbed for a period of time until they no longer pose a risk to human health and the local environment.

3 THE ERICA TOOL

Plants and animals may be exposed to ionising radiation in the environment from different sources, and under different types of exposure situations. In all of these, the factors contributing to the doses received can vary enormously, and various assessment tools have been developed which are able to model these contributing factors appropriately and systematically. One of the readily available assessment tools is ERICA that predicts the risk to RAPs from ionising radiation.

A variety of approaches are available for assessing radiological impacts on non-human biota. Of these approaches, the ERICA Tool has the most developed concentration ratio-based transfer database for a wide range of Reference Organisms, arguably giving it the best basis for prospective assessments when site-specific data are not available. It also considered the largest number of radionuclides included within the ICRP Publication 38 [9].

3.1 TECHNICAL BASIS OF THE ERICA TOOL

The ERICA Tool is a software program that guides the user through the assessment process, keeps records and performs the necessary calculations to estimate dose rates to selected biota. The Tool interacts with a number of databases and other functions that help the assessor to estimate environmental media activity concentration, activity concentration in biota, and dose rates to biota. The ERICA Tool also interfaces with the FREDERICA radiation effects database, which is a compilation of the scientific literature on radiation effect experiments and field studies, organised around different wildlife groups and, for most data, broadly categorised according to four effect umbrella endpoints: morbidity, mortality, reproduction and mutation.

The database of the ERICA tool has been built around a number of reference organisms. Each Reference Organism has its own specified geometry (and default transfer data) and is representative of terrestrial, freshwater or marine ecosystems.

The assessment elements of the ERICA integrated approach is organised in three separate tiers (Figure 1). Satisfying certain criteria in Tiers 1 and 2 allows the user to exit the assessment process while being confident that the effects on biota are low or negligible, and that the situation requires no further action. Where the effects are not shown to be negligible, the assessment should continue to Tier 3.

In the evaluation reported in this report, all assessments were undertaken at Tier 2. This was because Tier 2 allows the user the be more interactive than is the case with Tier 1 assessment, to change the default parameters and to select specific Reference Organisms. The evaluation is performed directly against the screening dose rate of 10 μGy h^{-1}.

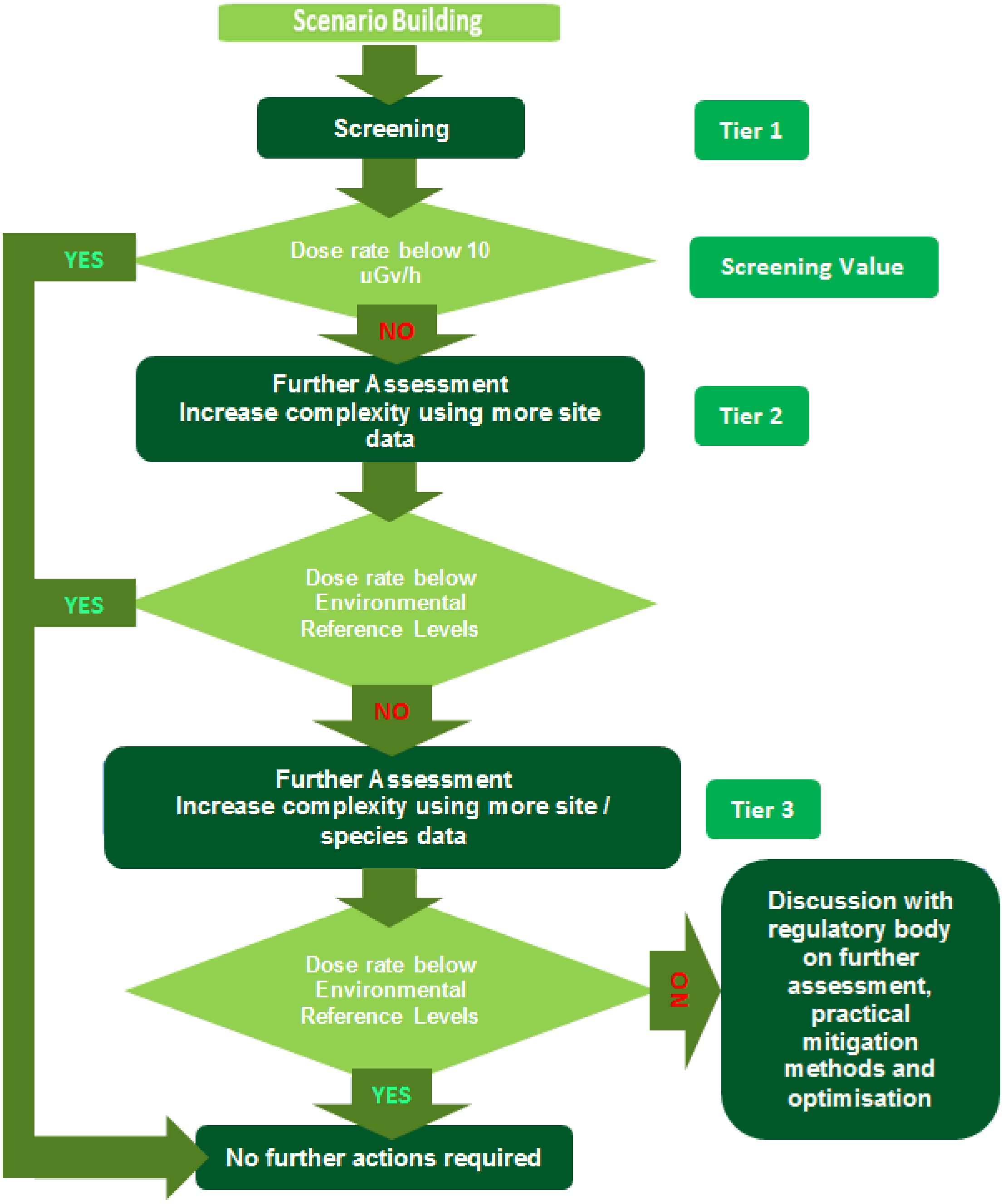

Figure 1: Tiered approach of ERICA Assessment using Screening Level Values

From ARPANSA (2015)

4 GEOGRAPHICAL AND ECOLOGICAL CONTEXT

4.1 GEOGRAPHICAL CONTEXT

The Proposal is located approximately 75 kilometres (km) north-east of Koolyanobbing, Western Australia. Access is via a 100 km road to the Intractable Waste Disposal Facility (IWDF) Mount Walton East (Crown Reserve No. 44102) that extends northward from the Boorabbin Siding on Great Eastern Highway; a 4.5 km westwards section along an existing road; and a 5.3 km northwards section of new site access road into the development envelope (See Figure 2)

There are no sensitive receptors within 5 km of the location of the Proposal. The nearest operation is the Class V IWDF Mount Walton East located approximately 6 km to the east, which operates on a campaign basis and does not have permanent residents. The nearest mining camp is the Carina Iron Ore Mine Accommodation Camp located approximately 52 km to the south east of Sandy Ridge.

The location of the Sandy Ridge Project has been specifically chosen to meet the requirements of International and National codes relating to the siting of a near surface geological repository. These site characteristics include:

- **Geologically stable** — the development envelope sits within the Archean Yilgarn Block and is geologically typical of areas overlying deeply weathered granite domes. It has very low seismicity (no earthquakes have been recorded at Sandy Ridge) and no volcanic or tectonic activity.
- **Natural geological barrier** — the clay bed is laterally extensive (80 km long and 40 km wide), has been stable for approximately 20 million years and is up to 36 m thick. This is capped by erosion resistant silcrete and laterite layers typically 4 to 6 metres thick in total.
- **Semi-arid desert Mediterranean climate** — averages just over 250 mm of rainfall per annum and evaporation is greater than 2,000 mm per annum. This means very little rainfall occurs across the site and generally water will evaporate before it infiltrates.
- **No surface water receptors** - there are no channels or creeks in the development envelope.
- **Very little (if any) surface water runoff** – Due to the low rainfall, high evaporation, permeable upper soil profile and gently sloping topography, significant rainfall events infiltrate quickly. There is a low likelihood of surface flows in the local catchments and any flows are short-lived and local in nature.
- **Lack of commercial mineral deposits** – there is no evidence to suggest that there is potential for economic mineral or hydrocarbon deposits beneath the kaolin deposit.
- **Topography** – the development envelope is flat to gently undulating and suitable for the construction of infrastructure and heavy vehicle movement.

- **Absence of Population** – located in an area with no population, the nearest population centre is a non-permanent camp approximately 52 km away.
- **Agricultural land use** – there is no potential for medium to high value agriculture.
- **Environmental values** – the environmental values of the development envelope are currently unknown and will be determined through investigation.
- **Heritage** – no special cultural or historical significance has been identified through a completed heritage study and consultation with stakeholders familiar with the area.
- **No flooding** – the development envelope is not subject to flooding, nor is it predicted to be in the future. The site is at very low risk of encountering cyclones.
- **Very low rates of erosion** – the development envelope is not subject to the erosive forces of high winds or rain due to the climate, soil types and topography and has been stable for thousands of years.

4.2 CURRENT ECOLOGICAL CONTEXT

The Public Environmental Review (PER) describes the potential impacts to fauna and flora species native to the area.

The following species potentially occur within the proposed development envelope due to the presence of suitable habitat, however, based on observations recorded during visits to the site, it was considered that there is little evidence to suggest the presence of these species. The list of species includes:

- Malleefowl (Leipoa ocellata).
- Rainbow Bee-eater (Merops ornatus).
- Cattle Egret (Ardea ibis).
- Great Egret, White Egret (Ardea alba).
- Fork-tailed Swift (Apus pacificus).
- Western Quoll (Dasyurus geoffroii).
- Ricinocarpos brevis (Shrub-like plant).
- Tetratheca paynterae / Paynter's Tetratheca (Shrub-like plant).
- Calytrix creswellii (Shrub-like plant).
- Lepidosperma lyonsii (Grass-like plant).

Australian species like the Kangaroo, Emu, Cockatoo and Echidna were also added for modelling purposes.

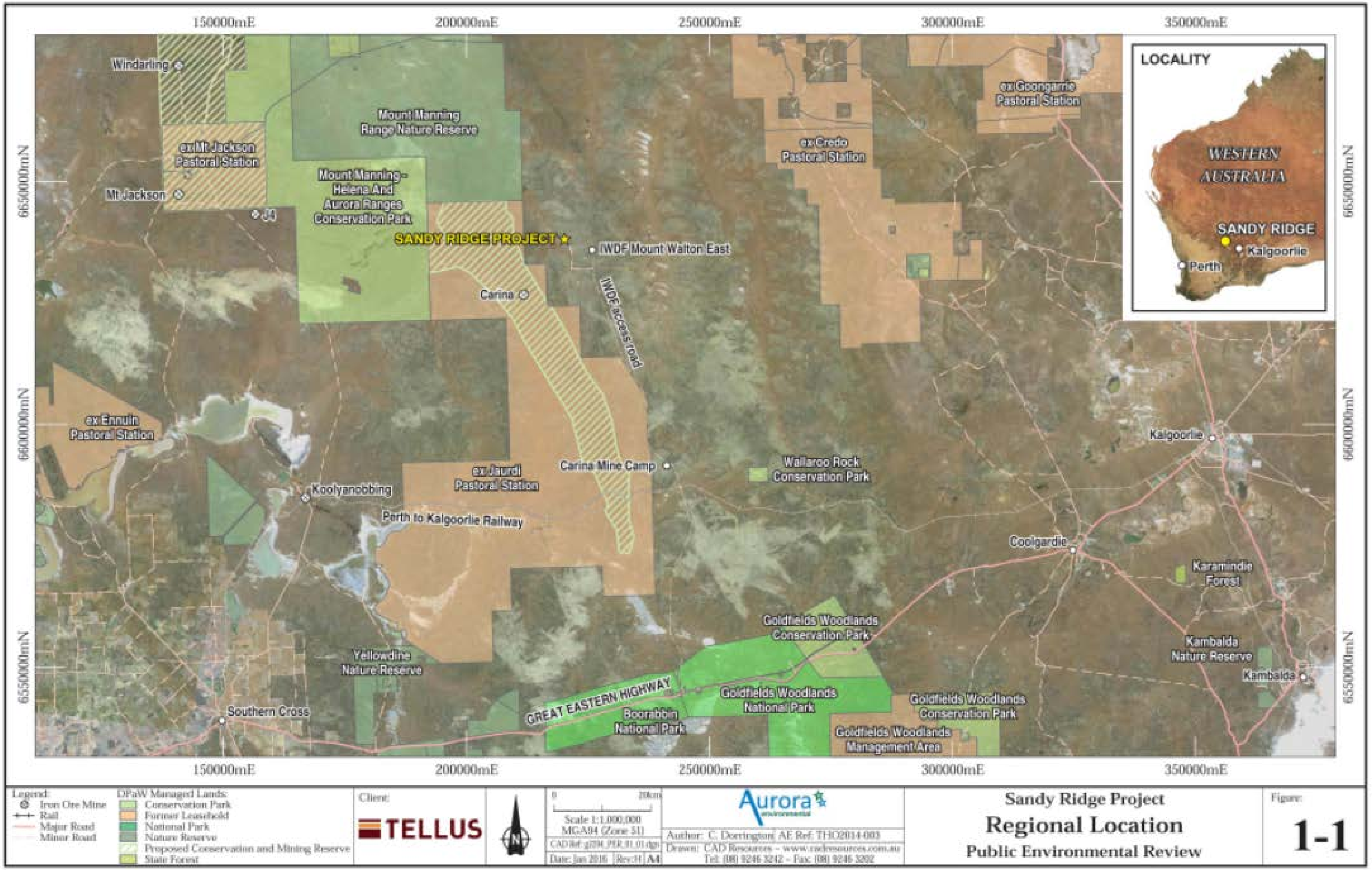

Figure 2 Location Map

5 OBJECTIVE

The framework for radiological protection of the environment is broadly consistent with that for radiation protection of people (Figure 3). The established framework, based on a concept developed by Pentreath (1998; 1999; 2002; 2004; 2005; 2009) uses Reference Plants and Animals (RAPs) as conceptual and numerical proxies to assess the relationships between exposure and dose (using simple dosimetric models), and between dose and effect (using Derived Consideration Reference Levels (DCRL) (also referred to as Environmental Reference Levels (ERL) in some literature) as numerical guides), for different taxa of flora and fauna (ARPANSA, 2010). It is applicable under all exposure situations, i.e. when activities and facilities that alter the radiation environment are planned and operating in a regulated manner (planned exposure situations), and in the case of dealing with existing exposure situations such as legacy sites.

As well as ensuring that humans are adequately protected from exposure to radiation and radioactive material stored and disposed of at the facility, there is a need to ensure that the environment as a whole is adequately protected.

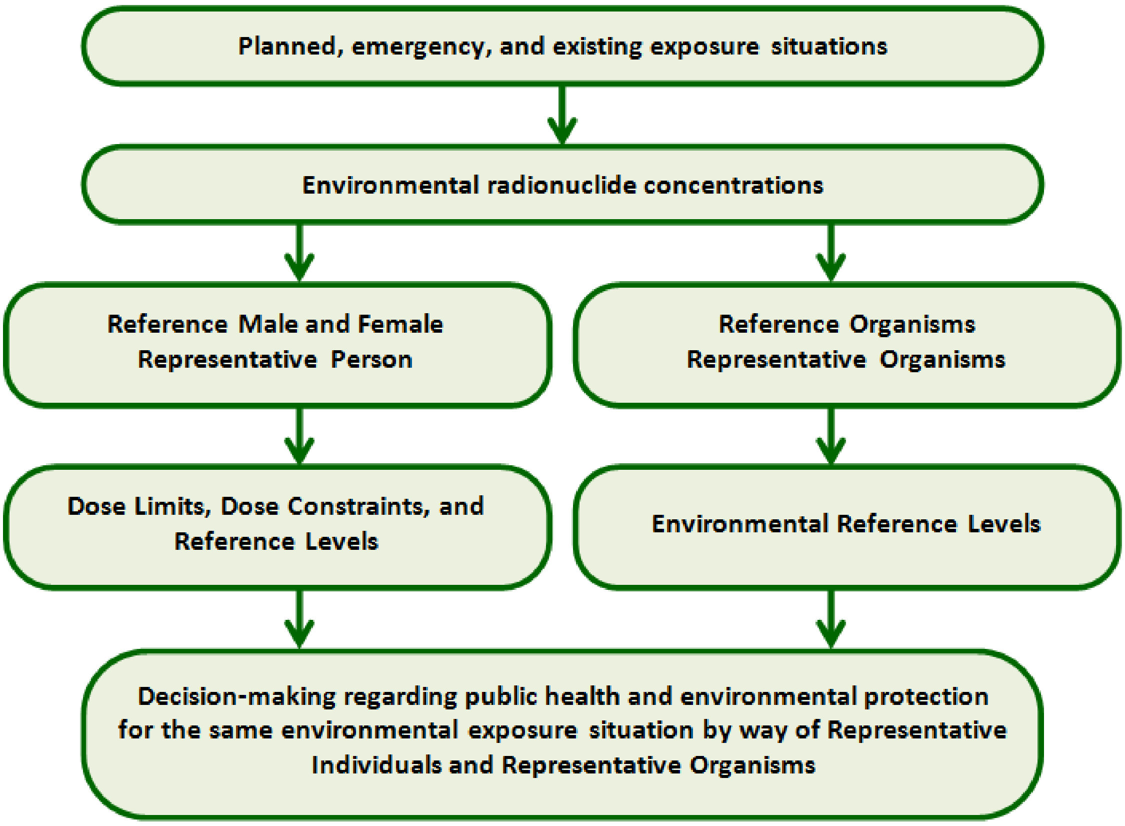

Figure 3: Framework for radiation protection of people (left) and wildlife (right)
(From ARPANSA (2015))

The objective of this assessment is to show that the radiological effects from the waste material stored and disposed of at the facility on the flora and fauna (all pathways of exposure), both during the periods of operation and closure, are at an acceptable level of risk and manageable to safeguard fauna and flora.

6 ASSESSMENT: BASIC CONCEPTS

This section outlines the basic concepts in assessment / decisions on protection of biota, namely: the dosimetric quantity; reference and representative organisms; and environmental reference levels.

6.1 DOSIMETRIC QUANTITY FOR PROTECTION OF NON-HUMAN SPECIES

The general approach to assessing potential or likely effects of ionising radiation on the health of fauna and flora involves estimations of the dose and/or the dose rate. The fundamental dosimetric quantity is the **absorbed dose**, i.e. the energy absorbed per unit mass of the material with which the radiation interacts. Absorbed dose is measured in the unit **gray** (Gy).

6.2 DEFINITION OF REFERENCE ORGANISMS

In the ERICA Tool, reference organisms are characterised by their dimensions, the concentrations of radionuclides that they exhibit relative to the environmental media with which they are associated and the fractions of the time that they are present within, or at the surface of, these various environmental media. The reference organisms selected for the ERICA Integrated Approach are listed in Table 1 below. They have been defined and used for the derivation of geometric relationships between radiation sources and organisms, as well as for considerations of the dosimetry of both external and internal exposure. The reference organisms can be grouped into three general ecosystem categories, namely terrestrial, freshwater and marine. In the current evaluation, only terrestrial organisms were considered.

Table 1: ERICA Reference Animals and Plants (RAPs)

Freshwater	Marine	Terrestrial
Amphibian *(frog)*	(Wading) bird *(duck)*	Amphibian *(frog)*
Benthic fish	Benthic fish *(flat fish)*	Bird *(duck)*
Bird *(duck)*	Bivalve mollusc	Bird egg *(duck egg)*
Bivalve mollusc	Crustacean *(crab)*	Detritivorous invertebrate
Crustacean	Macroalgae *(brown seaweed)*	Flying insects *(bee)*
Gastropod	Mammal	Gastropod
Insect larvae	Pelagic fish	Grasses and herbs *(wild grass)*
Mammal	Phytoplankton	Lichen and bryophytes

Freshwater	Marine	Terrestrial
Pelagic fish *(salmonid/trout)*	Polychaete worm	Mammal *(rat, deer)*
Phytoplankton	Reptile	Reptile
Vascular plant	Sea anemones/true coral	Shrub
Zooplankton	Vascular plant	Soil invertebrate (worm) *(earthworm)*
	Zooplankton	Tree *(pine tree)*

6.3 TERRESTRIAL REFERENCE ORGANISMS GEOMETRIES

One of the key practical purposes of reference organisms is to provide a means for the estimation of dose rates, where the ellipsoid can be used – by varying its axes – as a reasonable approximation for much of the existing wildlife on Earth (see Figure 4). Radiation damage arises from the ionisation that follows the path that radiation takes as it passes through tissues. Hence the dimensions of the organisms have relevance for the degree of radiation damage that may occur. These estimates, in turn, provide a basis for subsequent assessment of the likelihood and degree of radiation effects, using available effects information.

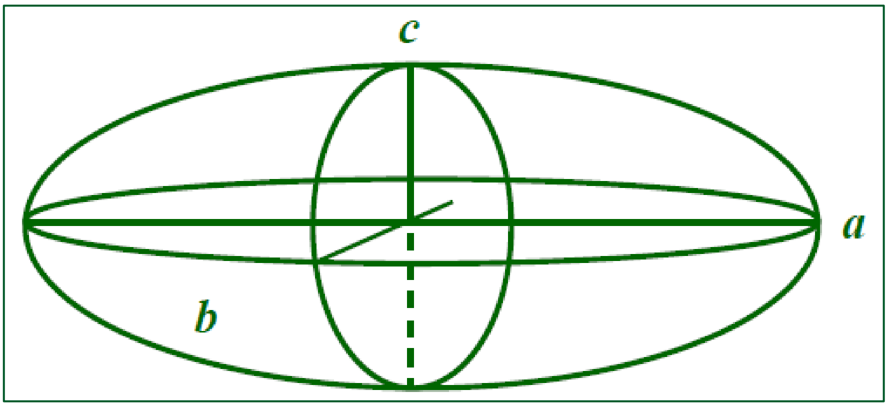

Figure 4: An ellipsoid, outlining the axes (a, b and c) that can be varied to accommodate for the different shapes of reference organism (image ARPANSA (2015)))

In summary, the simplifications introduced when using reference organisms include:

• the representation of different forms of fauna and flora by simple shapes (e.g. ellipsoids);

• an assumption of homogeneous radionuclide distribution in the tissues of the organism (internal dosimetry) and in environmental media (external dosimetry); and

• generic 'biology' in terms of habitat, occupancy, life cycle, reproduction and other factors.

Table 2: Geometries for some terrestrial fauna and flora species

Organism	Geometry defined by	Mass	Dimensions		
			Height	Width	Length
		kg	cm	cm	cm
Soil invertebrate (Worm)	ICRP - Earthworm	0.00524	1	1	10
Detritivorous invertebrate	FASSET - Woodlouse	0.00017	0.31	0.61	1.74
Flying insects	ICRP - Bee	0.000589	0.75	0.75	2.0
Gastropod	ERICA - Snail	0.0014	0.93	1.54	1.88
Lichen and bryophytes	ERICA - Bryophyte	0.00011	0.229	0.229	4.01
Grasses and herbs	ICRP – Wild Grass	0.00262	1.0	1.0	5.0
Shrub	ICRP – Wild Grass	0.00262	*1.0	*1.0	*5.0
Tree	ICRP – Pine Tree	471	30	30	1000
Mammal *(Rat)*	ICRP – Rat	0.314	5.0	6.0	20
Mammal *(Deer)*	ICRP – Deer	245	60	60	130
Bird	ICRP – Duck	1.26	8.02	10	30
Reptile	ERICA - Snake	0.744	3.49	3.49	116
Amphibian	ICRP - Frog	0.0314	2.5	3.0	7.99

**It was assumed that Shrubs has the same dimensions as grasses and herbs, since mass, ksi and chi are equal. Ksi (ξ) and chi (χ) are scaling parameters.*

from ARPANSA (2015)

In addition to these, representative fauna and flora species were included in the modelling to encompass species that may occur in the proposed development envelope (e.g. malleefowl) and are representative of the Australian landscape (e.g. emu).These are given in table 3.

Table 3:Geometries of Australian fauna and flora species

Organism	Geometry defined by	Mass	Dimensions		
			Height	Width	Length
		kg	cm	cm	cm
Malleefowl	Bird	2.5	11	13	33
Rainbow Bee-eater	Bird	0.027	3.252	3.252	4.878
Emu	Bird	50.0	38	36	70
Cockatoo	Bird	0.79	7.7	8.8	23.1
Cattle Egret	Bird	0.5	6.65	7.6	19.95
Great Egret	Bird	1	8.4	9.6	25.2
Fork-tailed Swift	Bird	0.035	3.54	3.54	5.31
Katydid Cricket	Insect	0.000589	0.75	0.75	2
Kangaroo	Mammal	54.0	36	36	76
Echidna	Mammal	4.5	13	18	37
Western Quoll	Mammal	1.1	9.12	7.6	30.4
Ricinocarpos brevis	Plant	0.00262	1	1	5
Paynter's Tetratheca	Plant	0.00262	1	1	5
Calytrix creswellii	Plant	0.00262	1	1	5
Lepidosperma lyonsii	Plant	0.00262	1	1	5

from ARPANSA (2015)

6.4 TERRESTRIAL REFERENCE ORGANISMS OCCUPANCIES

For the terrestrial ecosystem, the system becomes more complicated owing to the fact that for each reference organism only certain source-target configurations, i.e. presence of the reference organism at a specific place within its habitat, are permitted in the modelling. The permitted occupancies are provided in Table 4. Table 4 also summarises selected occupancies for additional species specific to the modelling

Table 4:Occupancy for selected terrestrial fauna and flora species

Reference Organism	In Soil	On Soil	In Air
Soil invertebrate (Worm) / Annelid	x		
Detritivorous invertebrate	x	x	
Flying insects		x	x[(a)]
Gastropod	x	x	
Lichen and bryophytes		x	
Grasses and herbs		x	
Shrub		x	
Tree		x	
Mammal *(Rat)*	x	x	
Mammal *(Deer)*		x	
Bird		x	x[(b)]
Reptile	x	x	
Amphibian	x	x	
Added Organism	**In Soil**	**On Soil**	**In Air**
Malleefowl		1	
Rainbow Bee-eater		1	
Emu		1	
Cockatoo		0.5	0.5
Cattle Egret		0.8	0.2
Great Egret		0.8	0.2
Fork-tailed Swift		0.5	0.5
Katydid Cricket	0.5	0.5	
Kangaroo		1	
Echidna	0.5	0.5	
Western Quoll	0.5	0.5	
Ricinocarpos brevis		1	
Paynter's Tetratheca		1	
Calytrix creswellii		1	
Lepidosperma lyonsii		1	

[(a)] DCC calculated for on soil
[(b)] DCC calculated for height of 3 m above ground level
For all in soil geometries, the DCC is derived using a 50-cm depth uniform volume source
For all on soil geometries and in air geometry for bird, the DCC is derived using a 10-cm depth uniform volume source

6.5 ENVIRONMENTAL SCREENING AND DERIVED CONSIDERATION REFERENCE LEVEL (DCRL'S)

DCRL's are dose rates to fauna and flora, excluding background levels, at which a more considered evaluation of the situation and the potential detriment to biota might be reasonable, and which should be considered in the over-all optimisation process (ARPANSA (2015).

DCRL can be considered as:

• A dose rate increment to fauna and flora above the natural and normal background level, which might result in detrimental health effects in the environment.

• A point of reference guiding optimisation, i.e. the level of effort expended on environmental protection, dependent on the overall management objectives and exposure situation.

As demonstrated in figure 5, the screening value of 10 µGy/h is the general default ERICA dose rate below which no effects at a population level to flora and fauna species are expected. (ARPANSA (2015))

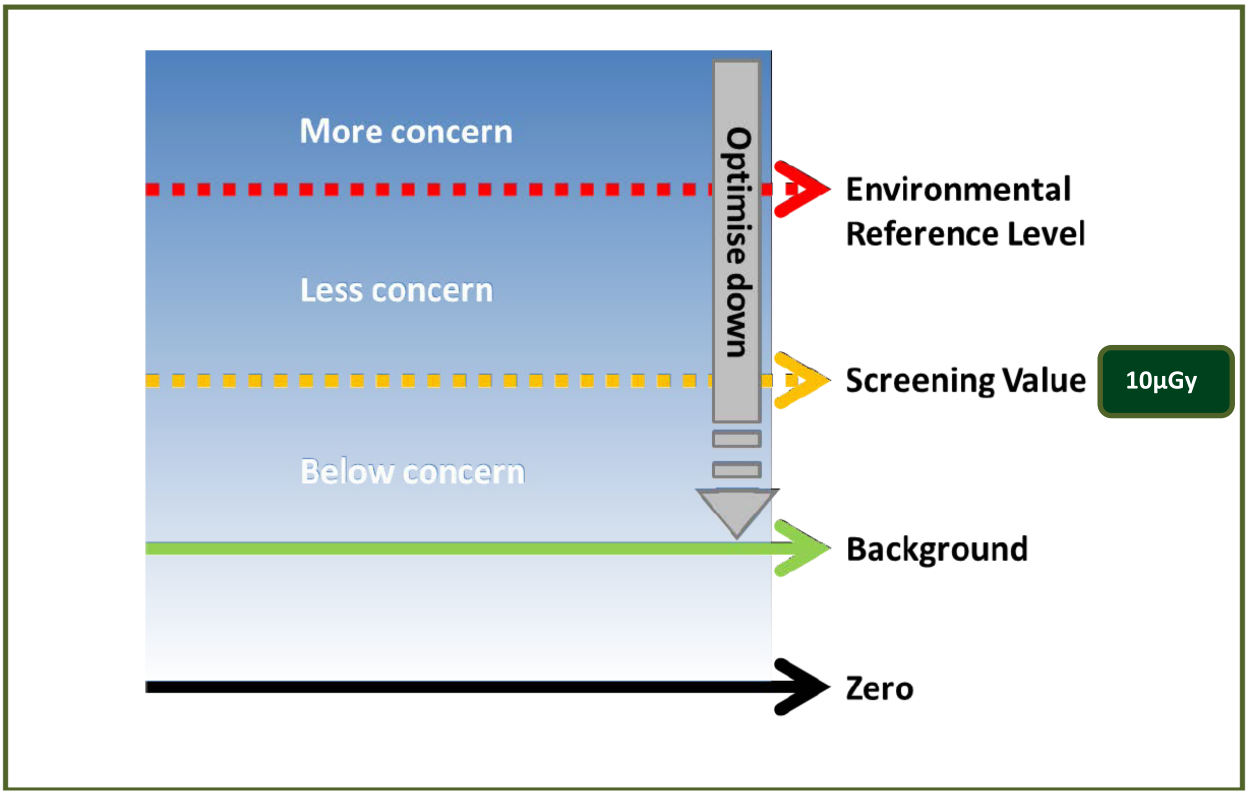

Figure 5: Use of environmental reference levels (or DCRL) and screening levels of dose rate for protection of the environment
(from ARPANSA (2015))

An international literature review has been conducted to derive exposure levels below which there is not expected to be significant population level effects for a range of organism types.

Different values have been derived for similar organisms due to the use of alternative data and/or application of differing levels of precaution. Note that (except where otherwise indicated) IAEA and UNSCEAR values refer to population effects, whereas ICRP give dose rate bands where effects may occur to individuals of that type of Reference Animals and Plants (RAPs).

Table 5: Summary of DCRL (µGy h-1) below which population level effects are not expected to occur

Organism	IAEA(1992)	UNSCEAR (1996,2011)	ICRP (2008)
Terrestrial Plants	400	100**	
Reference pine tree			4-40
Reference wild grass			40-400
Animals	40	40-100**	
Reference bee			400-4000
Reference earthworm			400-4000
Reference duck			4-40
Reference deer			4-40
Reference rat			4-40
Aquatic			
Freshwater organism	400	400	
Reference frog			40-400
Reference trout			40-400
Marine organism		400	
Reference crab			400-4000
Reference flatfish			40-400
Reference brown seaweed			40-400

*'Reference *organism type'* refers to the ICRP's Reference Animals and Plants (RAPs).

**Most highly exposed individuals.

7 ASSESSMENT OF RADIOLOGICAL IMPACTS ON FAUNA AND FLORA

In the current evaluation, four exposure scenarios were modelled using ERICA Tier 2 assessments:

- Scenario 1 – exposure of fauna and flora present in the area surrounding the radioactive waste warehouse.
- Scenario 2 – exposure to windblown material originating from operational stockpiles e.g. plant tails; ore, sand, laterite and silcrete stockpiles (during mining phase).
- Scenario 3 – exposure to windblown material originating from adhoc stockpiles e.g. radioactive materials received as bulk or from emergency clean-up operations.
- Scenario 4 – exposure post closure, with capping material and rehabilitation of the GSIF established as well as for the duration of the institutional control period.

Figure 6 is the conceptual infrastructure lay-out of the Proposal, overlain by areas relevant to modelled scenarios of exposure to fauna and flora during the operational phase (Scenarios 1 to 3) and post closure (Scenario 4).

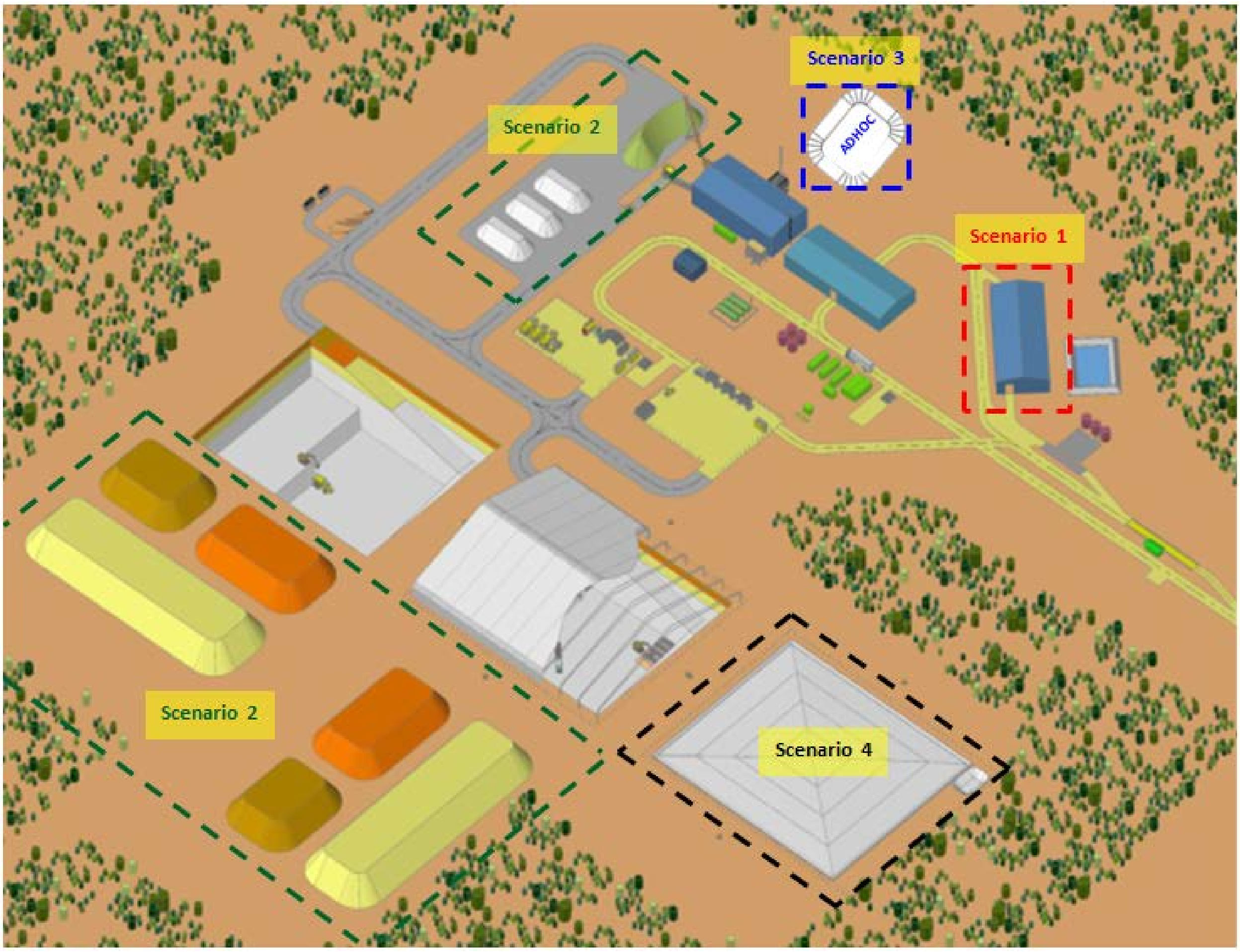

Figure 6: Conceptual Infrastructure Lay-out of the Sandy Ridge

Figure 7 shows the 7 m of capping material between the buried low level radioactive waste and the surface (Scenario 4).

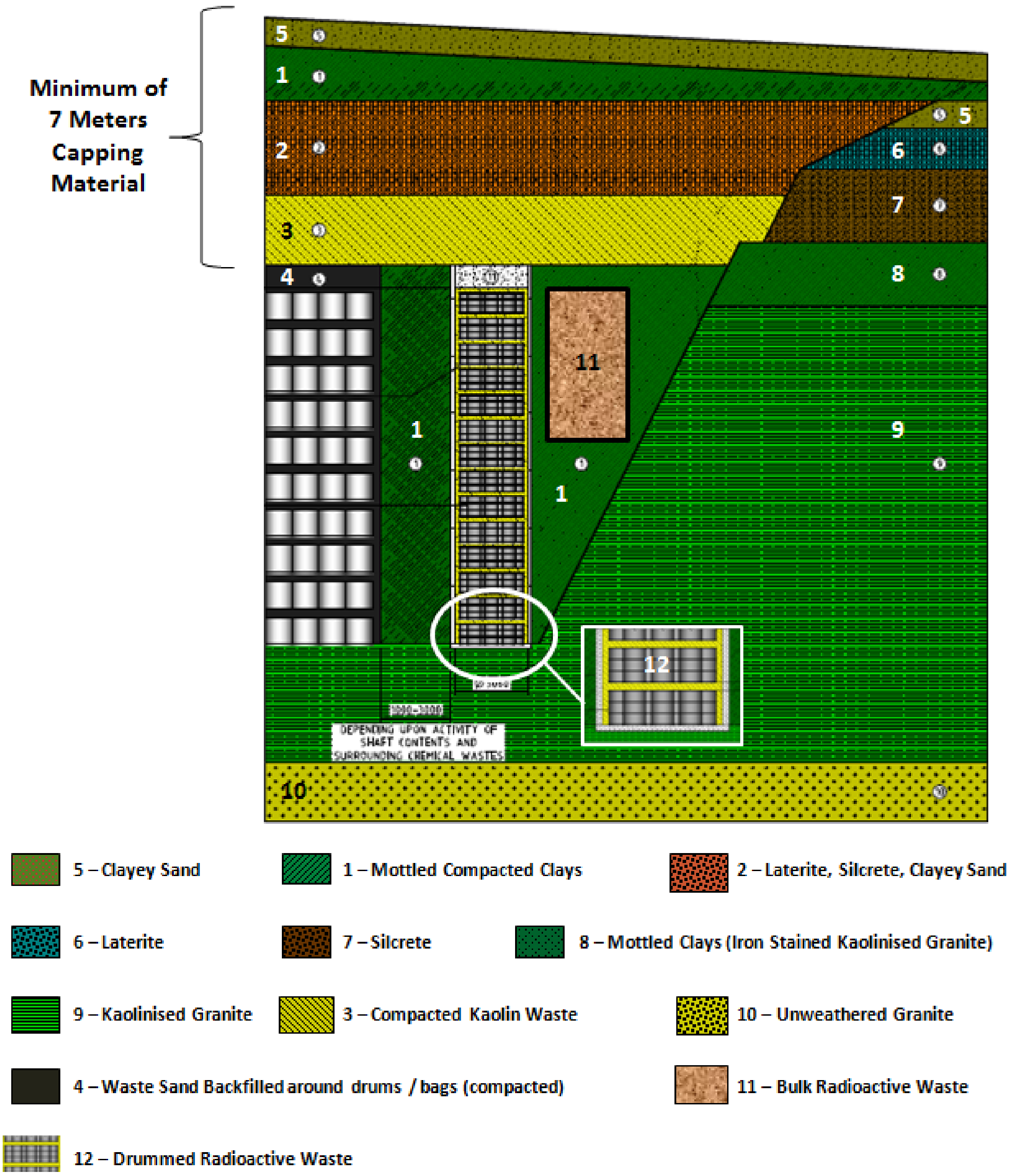

Figure 7 :Post Closure and Rehabilitation of the GSIF (Scenario 4)

7.1.1 ASSESSMENT OF RADIOLOGICAL IMPACTS TO FAUNA AND FLORA DURING THE OPERATIONAL PHASE OF THE PROJECT

Scenario 1 (exposure of fauna and flora present in the area surrounding the Radioactive Waste Warehouse)

As the facility will be accepting radioactive waste materials of various types, e.g. sealed sources, NORM containing pastes / sludges, contaminated solid material (e.g. plant equipment, laboratory PPE) and bulk contaminated soils or sands, an assessment was conducted to evaluate the potential radiological impact to fauna and flora surrounding the Radioactive Waste Warehouse used for storage of such materials.

According to RPS 5 [18], Section 5.1.2 (b), “a store for portable density / moisture gauges must be designed and constructed so that the radiation levels outside the store do not result in an ambient dose equivalent rate or directional dose equivalent rate, as appropriate, that exceeds 10 µSv/h”. Assuming a conversion of 1 µGy to 1 µSv, the Radioactive Waste Warehouse will be designed and constructed such that dose rates for all organisms present outside the facility are below the threshold dose rate of 10 µGy/h. No risk to any biota is therefore foreseen from material stored within the facility.

Specific controls for the various materials potentially stored at the facility are summarised below.

Sealed sources will upon receipt be stored in the Radioactive Waste Warehouse, unpacked, inspected and verified. After verification, sources will be secured in a 60 L drum inside a 200 L drum. Cement slurry will be added to the 60 L drum to fill all the void spaces and to cover all the items. The cement filled 60 L drums will be placed in the centre of a 200 L drum, which is then filled with concrete. The 200 L drum will be marked with its identification number and labelled. These drums will be stored until the shaft is prepared for disposal. It is not foreseen that any contact with or dispersal of sources into the environment would be a likely scenario. No ERICA modelling has therefore been conducted using sealed sources as environmental media.

NORM containing pastes, sludges or liquids, will be stored in the Radioactive Waste Warehouse or in sea containers on hardstand (dependent upon activity). In campaigns waste will be unpacked, inspected and verified by laboratory testing. If required the waste will then be treated with absorbent and pozzolanic materials to form a slurry which will solidify and stabilise the waste. The slurry can be poured into drums, moulds, or contained sections of the cell where it will set. Again, it is not foreseen that any contact with or dispersal of these materials into the environment would be a likely scenario, given the controls intended. One scenario has however been modelled using radium sludge as environmental media, to simulate the unlikely event of bulk storage of spadeable sludge on stockpiles with the potential to create pathways of distribution to the surrounding environment.

Contaminated solid material will be stored in Radiation Store building or in sea containers on hardstand (dependent upon activity) until suitable space is available in cell. Depending upon physical size and shape of materials, type and activity of radiation, these wastes can either be:

- Compacted in drums and filled with kaolin or cement grout prior to disposal.
- Crushed or cut to remove void space and fill remaining voids in with cement grout or kaolin solids.
- If necessary, place entire sea-container in cell, cut holes in top and fill all void space with cement grout.

It is not foreseen that any contact with or dispersal of the materials (as described for Scenario 1 above) into the environment would be a likely scenario, given the controls intended.

Scenario 2 (exposure to windblown material originating from operational stockpiles e.g. plant tails; ore, sand, laterite and silcrete stockpiles).

As plant tails, kaolin ores, and other bulk materials will be stockpiled during the operational phase of the project, the potential exist for these materials to be distributed into the surrounding environment through e.g. wind-, water- and material handlings actions, therefore potentially impacting on local fauna and flora. It is foreseen that such materials would be NORM-containing nuclides of the U-238, U-235 and Th-232 decay series.

A matrix of activity concentrations (per biota type) was therefore calculated which, when modelled, would give rise to dose levels (µGy h-1) below which species population level effects are not expected to occur. In creating this matrix, a Th-232 to U238 activity (Bq/g) ratio of 1 : 1 was assumed. Natural uranium was also assumed, i.e. the same isotopic ratio found in nature between U-235 and U-238, rendering an activity ratio of U-235 = 0.045 x U-238 with all chains being in Secular equilibrium.

Scenario 3 (exposure to windblown material originating from adhoc stockpiles e.g. radioactive materials received as bulk or from emergency clean-up operations)

Bulk contaminated soils or sands will be delivered to site in either bulka bags, shipping containers or as wetted down sand, depending on volume and physical characteristics of material. Practical transport will be arranged to coincide with a disposal campaign so it can be disposed of directly into pit, but if not viable, the material will be stored in the Radioactive Waste Warehouse. For large volumes of material, separate stockpile areas will be set up (adhoc stockpiles), and dust control measures introduced. These are discussed in section 9.2 of the radiation management plan and include a designated stockpile area with concrete slab and bunded walls, closing stockpile with tarp material, dust suppression agents and a monitoring program to confirm efficiency of controls implemented.

ERICA Modelling was conducted on adhoc stockpiles with the potential to be released into the environment as result of e.g. windblown dispersal, thus potentially affecting local biota. It is foreseen that such materials would be NORM-containing nuclides of the U-238, U-235 and Th-232 decay series. No controls were considered in this assessment to demonstrate worst case scenario exposure conditions.

To form a baseline for potential radionuclide activity concentrations to be used as inputs into modelling scenarios, industry information on typical activity ranges of various type of potential bulk wastes, along with Category A and Category C waste (NHMRC, 1992) were collated as per Table 6.

Table 6: – Typical industry and waste-characterised activity ranges as per Australian regulation

Nuclide	Activity Concentration (Bq/g)							
	U & Th Sands*	Radium Scale#	Radium Sludge#	Oil & Gas+	Category A Waste@	Category C Waste@	VLLW^	LLW^
Pa-231	0.7						14.3	57.1
Pb-210	10	0.02-75	0.1-1300		≤ 5	5 - 500		
Po-210	4	0.02-1.5	0.004-160		≤ 5	5 - 500		
Ra-226	10	0.1-15000	0.05-800	1400	≤ 5	5 - 500	14.3	57.1
Ra-228	70	0.05!-2800	0.5-50	1587	≤ 10	5 - 500		
Th-227	0.5							
Th-228	70				≤ 10	5 - 500		
Th-230	11				≤ 5	5 - 500	14.3	57.1
Th-232	60	0.001-0.002	0.002-0.01		≤ 10	5 - 500	14.3	57.1
U-234							14.3	57.1
U-235	0.5						14.3	57.1
U-238	10	0.001-0.5	0.005-0.01		≤ 5	5 - 500	14.3	57.1
Total Activity concentration of Long-Lived alphas with T1/2 > 40 years:							1 - 100	100 - 400

* With reference to [1], Section 4.2.2
+ With reference to [1], Section 4.2.3
# Radium Scale & Sludge as per Table 19, Section 12.2.3 of [2]. For modelling purposes, the upper scale concentrations were used.
! Radium Scale as per Table 4, Section 1.8 of [3].
@ Category A and Category C Waste as per Secular Equilibrium Conditions [4], [5] and [6]. For modelling purposes, the upper scale concentrations were used.
Note that U-235 chain for Category A & C wastes, alpha and beta/gamma emitters' limits are very high and thus not included, since limiting nuclides are alphas of the Th-232 and U-238 chains
^ NORM with T1/2 > ~ 40 years as per [7] - long-lived alphas from the U-238, U-235 and Th-232 decay chains. The assumption was made that boundaries between VLLW, LLW and ILW refer to total activity (i.e. summation of long-lived alpha activity concentrations) and that decay chains are in secular equilibrium

7.1.2 ASSESSMENT OF RADIOLOGICAL IMPACTS TO FAUNA AND FLORA POST CLOSURE AND REHABILITATION

Scenario 4 (exposure post closure, with capping material and rehabilitation of the cell established as well as for the duration of the institutional control period).

To determine whether a minimum cover thickness of 7 meters (upon closure) would provide sufficient shielding from encapsulated waste material, an estimate of unshielded gamma dose rate is required combined with the half-value-layer of the material used for the cover (shielding material). The following mathematical equations are relevant and were used to determine whether cover shielding would be sufficient for each of the waste material types listed in Table 6.

Unshielded dose rate: $I_0 = \Gamma A / d^2 = \Gamma$ x Activity / (distance from waste source)^2

Where:

I_0= intensity (or dose rate) before shielding (µSv/h)

Γ= Dose conversion factor: Dose rate (µSv/h) at 1 m from a source per 1 GBq activity of the source

A = Activity of the source (GBq)

d = distance from the source (m)

Shielded dose rate: $I = I_0 / 2^n$

Where

I = intensity (or dose rate) after shielding (µSv/h)

I_0= intensity (or dose rate) before shielding (µSv/h)

n = number of half value layers (assumed that cover material would be Packed Soil[!] i.e. 7 m minimum cover material would relate to 77 halve value layers)

[!] As various materials are used for cover materials with various densities, a density (1.99 g/cm^3) of Packed Soil, with a Halve value layer of 9.1 cm (0.091 m) have been assumed

Table 7: Dose Rate (gamma) resulting from various waste material types before and after covering with 7 m of capping material

Description	Waste material Type								Criteria Activity
	U & Th Sands*	Radium Scale#	Radium Sludge#	Oil & Gas#	Cat A Waste@	Cat C Waste@	VLLW@	LLW@	
Ref Nuclide Selected	Th-232*	Ra-226#	Ra-226#	Ra-226#	Th-232	Th-232	Th-232@	Th-232@	Th-232
Activity Concentration of Source	70 Bq/g	17800 Bq/g	850 Bq/g	3000 Bq/g	15 Bq/g	1000 Bq/g	100 Bq/g	400 Bq/g	3700 Bq/g
Source Activity^	1.75E+05	4.45E+07	2.13E+06	7.50E+06	3.75E+04	2.50E+06	2.50E+05	1.00E+06	9.25E+06
I_0= intensity before shielding$ µSv/h	4.20E+08	9.92E+11	4.74E+10	1.67E+11	9.00E+07	6.00E+09	6.00E+08	2.40E+09	2.22E+10
I = intensity after shielding µSv/h	2.9E-15	6.9E-12	3.3E-13	1.2E-12	6.3E-16	4.2E-14	4.2E-15	1.7E-14	1.5E-13

*Th-232 is the dominant nuclide in Mineral Sands and the Head-of-Chain (U-238 + Th-232) activity concentration was assigned to Th-232 for calculation purposes

#Ra-226 selected as the dominant nuclide in the Oil & Gas, Radium Scale and Radium Sludge wastes and Ra-226 + Ra-228 activity concentration was assigned to Ra-226 for calculation purposes

@Th-232 selected as the dominant nuclide in Category A, Category C, VLLW and LLW and total chain activity concentration was assigned to Th-232 for calculation purposes

^Activity of Sources calculated based on a mass of 2,000,000 tonne (total waste after 25 years production) per material type

$ I_0 taken at a distance (d) from the source of 10 cm (0.1 m)

! As various materials are used for cover materials with various densities, a density (1.99 g/cm^3) of Packed Soil, with a Halve value layer (HVL) of 9.1 cm (0.091 m) have been assumed

As demonstrated from Table 7, external gamma dose rate on the surface post closure (minimum cover of 7 m) would be negligible (background radiation levels), even if all radioactive waste (2,500,000 tonnes) placed in the cell was high activity concentration radium scales at an activity concentration of 17800 Bq/g radium (Ra-226 and Ra-228 combined). Calculation demonstrates that the thickness of the cell capping layers will be a sufficient control measure to reduce radiation levels at the surface of the cell. Therefore no radiation impacts will occur to plants and animals that grow, use or traverse the cell caps during the institutional control period.

Radiation exposure to fauna and flora (post closure) would therefore be only as a result of any radiation present in the top layer of cover material. ERICA Modelling was therefore conducted assuming that the top layer of cover material would have similar radiological characteristics to background soils in the surrounding environment. A cover uranium content of 11 ppm [8] was therefore accepted (as representative of background soil) with the further assumption that thorium would also be present at 11 ppm. Assuming secular equilibrium and an activity ratio of U-235 = 0.045 x U-238, activity concentrations of individual nuclides were calculated as per Table 8.

If radionuclide levels in the cap material are at or below those given in Table 8 there will be no risk to Fauna and Flora residing on the cap.

Table 8:Activity concentrations (Bq/g) of the top layer of cover material upon closure

Nuclide	Activity Concentration (Bq/g) Closure Capping Material$
Pa-231	0.006
Pb-210	0.14
Po-210	0.14
Ra-226	0.14
Ra-228	0.04
Th-227	0.006
Th-228	0.04
Th-230	0.14
Th-232	0.04
U-235	0.006
U-238	0.14

$ Regional sampling of the granite shows the uranium content to be consistently at or below 11ppm [8]. The assumption was made that Th-232 ppm is equal to that of U-238, that U-235 to U-238 ratio is 0.045 (based on activity concentration) and that all three decay chains are in secular equilibrium.

8 FINDINGS AND CONCLUSIONS

8.1 FINDINGS

Appendix A to I summarises results of the various ERICA modelling assessments done per material type, detailing the following: activity concentration of source media (Bq/kg) to which biota are exposed; contributions of individual radionuclides to total, internal and external dose rate for each organism; and activity concentration or individual radionuclides transferred from source media into living organisms.

Scenario 1 (exposure of fauna and flora present in the area surrounding the radioactive waste warehouse)

The Radioactive Waste Warehouse will be designed and constructed such that dose rates for all organisms present outside the warehouse are below the threshold dose rate of 10 Gy/h. No risk to any biota is therefore foreseen from material stored within the Radioactive Waste Warehouse

Scenario 2 (exposure to windblown material originating from operational stockpiles e.g. plant tails; ore, sand, laterite and silcrete stockpiles).

A matrix of activity concentrations (per biota type) was calculated which, when modelled, would give rise to dose levels (µGy h-1) below which species population level effects (derived effect levels) are not expected to occur. This activity concentration matrix is summarised in Table 9.

Table 9: Matrix of calculated activity concentrations (per species type) giving rise to dose levels below which species population level effects are not expected to occur

Organism Group	ERICA Screening Level	Derived Effects Levels (µGy/h)	
	10 µGy/h[$]	40 µGy/h	400 µGy/h
Plants (Shrubs & Grasses)[@]	0.25*	1*	10* - 11*
Plants (Trees)[#]	3.5*	15*	160*
Birds[#]	3*	12* – 13*	120* - 130*
Mammals Large[#]	1.8*	8*	80*
Mammals Small[#]	1.5* – 1.8*	6* – 7*	60* - 75*
Insects - Flying[@]	1.5* - 2*	7* - 9*	90*
Insects – Ground dwelling[@]	1.5* - 2*	7* - 9*	68* -85*

*Head of Chain activity concentration (Bq/g), i.e. Bq/g Th-232 + Bq/g U-238
Assumed Th-232: U238 activity (Bq/g) ratio of 1: 1
U-235 and U-238 activity ratio of U-235 = 0.045 x U-238
All decay chains assumed to be in Secular equilibrium
[@]Organisms with DCRL levels at 400 µGy/h
[#]Organisms with DCRL levels at 40 µGy/h

$ERICA Environmental Screening level

Scenario 3 (exposure to windblown material originating from adhoc stockpiles e.g. radioactive materials received as bulk or from emergency clean-up operations)

Table 10 is a summary of modelled total dose rate (per species evaluated) as a result of exposure to typical industry waste and Australian waste categories. As a first approach, the extreme condition was modelled, assuming that all organisms are exposed 100 percent of the time to stockpiled material i.e. simulating a condition of living on top of waste stockpiles or burrowing within.

Table 10: Total dose rate per organism exposed to different waste materials at 100% occupancy of the site

Organism	Total Dose Rate (µGy/h)							
	U & Th Sands	Radium Scale	Radium Sludge	Oil & Gas	Category A Waste	Category C Waste	VLLW	LLW
Grasses & Herbs	2697.4	3.7E+05	2.1E+04	3.52E+04	542.6	3.7E+04	680.0	2719.8
Malleefowl	92.8	8.0E+04	4.3E+03	7.75E+03	33.8	3.1E+03	91.0	363.8
Rainbow Bee-eater	96.3	8.1E+04	4.4E+03	7.83E+03	34.4	3.2E+03	91.5	365.9
Shrub	1445.4	6.8E+05	3.8E+04	6.39E+04	425.9	3.6E+04	851.6	3406.2
Bird	97.8	8.3E+04	4.5E+03	8.05E+03	35.2	3.2E+03	93.8	375.0
Echidna	142.5	1.0E+05	5.8E+03	9.77E+03	55.1	5.1E+03	323.8	1295.2
Emu	84.7	7.9E+04	4.3E+03	7.59E+03	32.4	3.0E+03	89.8	359.2
Flying insects	177.8	9.4E+04	5.2E+03	9.07E+03	50.6	4.3E+03	146.0	583.9
Annelid	308.0	1.0E+05	5.7E+03	1.03E+04	73.5	5.7E+03	215.0	860.2
Amphibian	181.4	1.0E+05	6.1E+03	1.04E+04	64.7	5.8E+03	160.8	643.2
Cockatoo	93.9	8.1E+04	4.3E+03	7.77E+03	34.0	3.1E+03	91.1	364.4
Kangaroo	130.2	1.2E+05	6.3E+03	1.10E+04	49.3	4.7E+03	342.5	1370.0
Kytydid Cricket	210.6	1.0E+05	5.5E+03	9.85E+03	56.6	4.7E+03	151.6	606.5
Mammal - large	108. 8	9.6E+04	5.5E+03	9.08E+03	49.4	4.8E+03	319.1	1276.4
Mammal - small	179.5	1.0E+05	5.9E+03	1.03E+04	61.2	5.5E+03	326.9	1307.7
Reptile	210.7	1.0E+05	6.1E+03	1.03E+04	71.1	6.3E+03	327.5	1310.0
Tree	76.2	2.9E+04	1.9E+03	2.90E+03	28.5	2.5E+03	38.4	153.6
Cattle Egret	95.0	8.1E+04	4.4E+03	7.80E+03	34.2	3.1E+03	91.3	365.1
Great Egret	94.2	8.1E+04	4.4E+03	7.78E+03	34.0	3.1E+03	91.2	364.6
Fork-tailed Swift	95.1	8.1E+04	4.4E+03	7.80E+03	34.2	3.1E+03	91.3	365.1
Western Quoll	149.6	1.0E+05	5.8E+03	9.92E+03	56.3	5.2E+03	324.8	1299.1
Ricinocarpus brevis	1455.2	6.9E+05	3.9E+04	6.49E+04	429.3	3.6E+04	861.7	3446.7
Paynter's Tetratheca	1455.2	6.9E+05	3.9E+04	6.49E+04	429.3	3.6E+04	861.7	3446.7
Calytrix Creswellii	1455.2	6.9E+05	3.9E+04	6.49E+04	429.3	3.6E+04	861.7	3446.7
Lepidosperma Lyonsii	2709.2	3.8E+05	2.2E+04	3.58E+04	545.3	3.8E+04	684.7	2738.8

These results demonstrate that modelled dose rates for all organisms exposed to stockpiled waste material for 100 percent of the time are well above the threshold dose rate of 10 μGy/h.

Dose rate to all grass and shrub-like plant species are also above the DCRL of 400 μGy/h upon exposure to any of the waste materials evaluated. Dose to insect species exposed to U and Th Sands, Category A waste or VLLW materials are below the DCRL of 400 μGy/h, but full-time exposure to other waste materials predicted doses above DCRL.

Dose rate to all mammals (large and small) are above the DCRL of 40 μGy/h upon exposure to any of the waste materials evaluated. Dose to bird species and to trees exposed to Category A waste is below the DCRL of 40 μGy/h, but full-time exposure to other waste materials predicted doses above DCRL.

Scenario 4 (exposure post closure, with capping material and rehabilitation of the GSIF established as well as for the duration of the institutional control period).

As demonstrated in Section 6.2.2 of this report, external gamma dose rate on the surface of the cell caps post closure (minimum cover of 7 m) would be negligible, even if all radioactive waste (2,500,000 tonnes) would be high activity concentration radium scales at an activity concentration of 17800 Bq/g radium (Ra-226 and Ra-228 combined). This calculation demonstrates that the thickness of the cell capping layers will be a sufficient control measure to reduce radiation exposure at the surface of the cell. Therefore no radiation impacts will occur to plants and animals that grow, use or traverse the cell caps during the institutional control period

Table 11 summarises species' total dose rate upon closure (as result of exposure to the top layer of the capping material), i.e. after establishment of capping the waste with 7 meters of material.

Table 11: Total dose rate per organism post-closure

Organism	Total Dose Rate (μGy/h)
	Closure Capping Material
Grasses & Herbs	7.2
Malleefowl	0.8
Rainbow Bee-eater	0.8
Shrub	8.7
Bird	0.8
Echidna	1.4
Emu	0.8
Flying insects	1.1
Annelid	1.3
Amphibian	1.5
Cockatoo	0.8
Kangaroo	1.3

Organism	Total Dose Rate (μGy/h)
	Closure Capping Material
Kytydid Cricket	1.1
Mammal - large	1.4
Mammal - small	1.5
Reptile	1.7
Tree	0.6
Cattle Egret	0.8
Great Egret	0.8
Fork-tailed Swift	0.8
Western Quoll	1.4
Ricinocarpus brevis	8.8
Paynter's Tetratheca	8.8
Calytrix Creswellii	8.8
Lepidosperma Lyonsii	7.2

Upon closure and during the institutional control period, the modelling demonstrates that dose rates for all organisms are below the threshold dose rate of 10 μGy/h. No risk to any biota is therefore foreseen when wastes are sufficiently capped.

8.2 CONCLUSIONS & RECOMMENDATIONS

From the Scenario 3 modelling, it was indicated that exposure to stockpiled waste material at full-time occupancy could result in radiological impacts too high for adequate protection of non-human biota, it is imperative to ensure that stockpiled radioactive bulk materials are sufficiently contained to prevent windblown (or other) dispersal to the surrounding environment. It is also recommended to establish control measures preventing fauna species access to stockpiled bulk materials or pits during the operational phase of the project. The controls that will be implemented to ensure the risk is mitigated and are discussed in the waste management plan

From the Scenario 1 modelling (exposure of fauna and flora present in the area surrounding the radioactive waste warehouse), and under the condition that the storage warehouse will be designed and constructed such that dose rates for all organisms present outside the warehouse are below the threshold dose rate of 10 μGy/h, no risk to any biota is therefore foreseen from material stored within the radioactive waste warehouse.

Upon closure, with a minimum capping of 7 meters, and for the duration of the institutional control period, no risk to non-human biota is foreseen, as modelled dose rates for all organisms are below the threshold dose rate of 10 μGy/h.

9 DEFINITIONS & ACRONYMS

Absorbed Dose – The energy deposited within any material by the passage through it of ionising radiation (Grays: 1 Gy = 1 joule / kg)

Activity concentration – means the concentration of a radioactive substance in any particular material expressed in terms of the activity of the radionuclide in Becquerel per kilogram of the material.

Biosphere – that part of the environment that is normally inhabited by living organisms and is taken generally to include those elements of the environment, including groundwater, surface water and marine resources, that are used by people or accessible to people.

Contamination – Releases to the wider environment of chemicals, including radionuclides, from human activities.

Derived consideration reference level (DCRL) – a band of dose rate within which there is likely to be some chance of deleterious effects of ionising radiation occurring to individuals of that type of reference animal of plant (derived from a knowledge of defined expected biological effects for that type of organism) that, when considered together with other relevant information, can be used as a point of reference to optimise the level of effort expected on environmental protection, dependent upon the overall management objectives and the relevant exposure situation. DCRL is conceptually equivalent to environmental reference levels (ERL).

Dose Rate – the average level of dose that any material or biota is exposed to over time (typically measured in mGy/h).

Environmental Media- oil, water, air, biota (plants and animals), or any other parts of the environment that can contain contaminants.

Environmental Reference Levels (ERL) - see Derived Consideration Reference Level (DCRL)

ERICA – Environmental Risk from Ionising Contaminants Assessment

Existing Exposure Situation – a situation of exposure that already exists when a decision regarding the need for control is required, including prolonged exposure situations after emergencies.

Modelling – the estimation of environmental media concentrations and / or dose or dose rate using equations to emulate natural processes. As far as possible, extant data are used to parameterise the equations but assumptions need to be made where adequate data do not exist.

Reference organism – an entity that provides a basis for the estimation of radiation dose rate to any living organism that is typical, or representative, of an impacted environment.

RAPs (Reference Animals and Plants) – a hypothetical entity, with the assumed basic biological characteristics of a particular type of animal or plant, as described to the generality of the taxonomic level of family, with defined anatomical, physiological, and life history properties, that can be used for the purpose of relating exposure to dose, and dose to effect, for that type of living organism.

Screening level – the absorbed dose rate to an organism above which further considerations or investigations are warranted.

Sealed source – means controlled material permanently contained in a capsule, or closely bound in a solid form, that is strong enough to be leak-tight for (a) the intended use of the controlled material and (b) any foreseeable abnormal events likely to affect the controlled material.

Storage – means the emplacement of waste in a facility with the intent and in a manner such that it can be retrieved at a later time.

Taxonomy – the branch of science concerned with classification, especially of organisms.

Waste acceptance criteria – quantitative or qualitative criteria specified by the regulatory body, or specified by an operator and approved by the regulatory body, for radioactive waste to be accepted by the operator of a repository for disposal, or by the operator of a storage facility for storage. Waste acceptance requirement might include, for example, restrictions on the activity concentration or the total activity or particular radionuclides (or type of radionuclide) in the waste or requirements concerning the waste form or waste package.

Waste disposal – means the placement of radioactive waste in a structure and in a manner such that there is no intention of retrieval.

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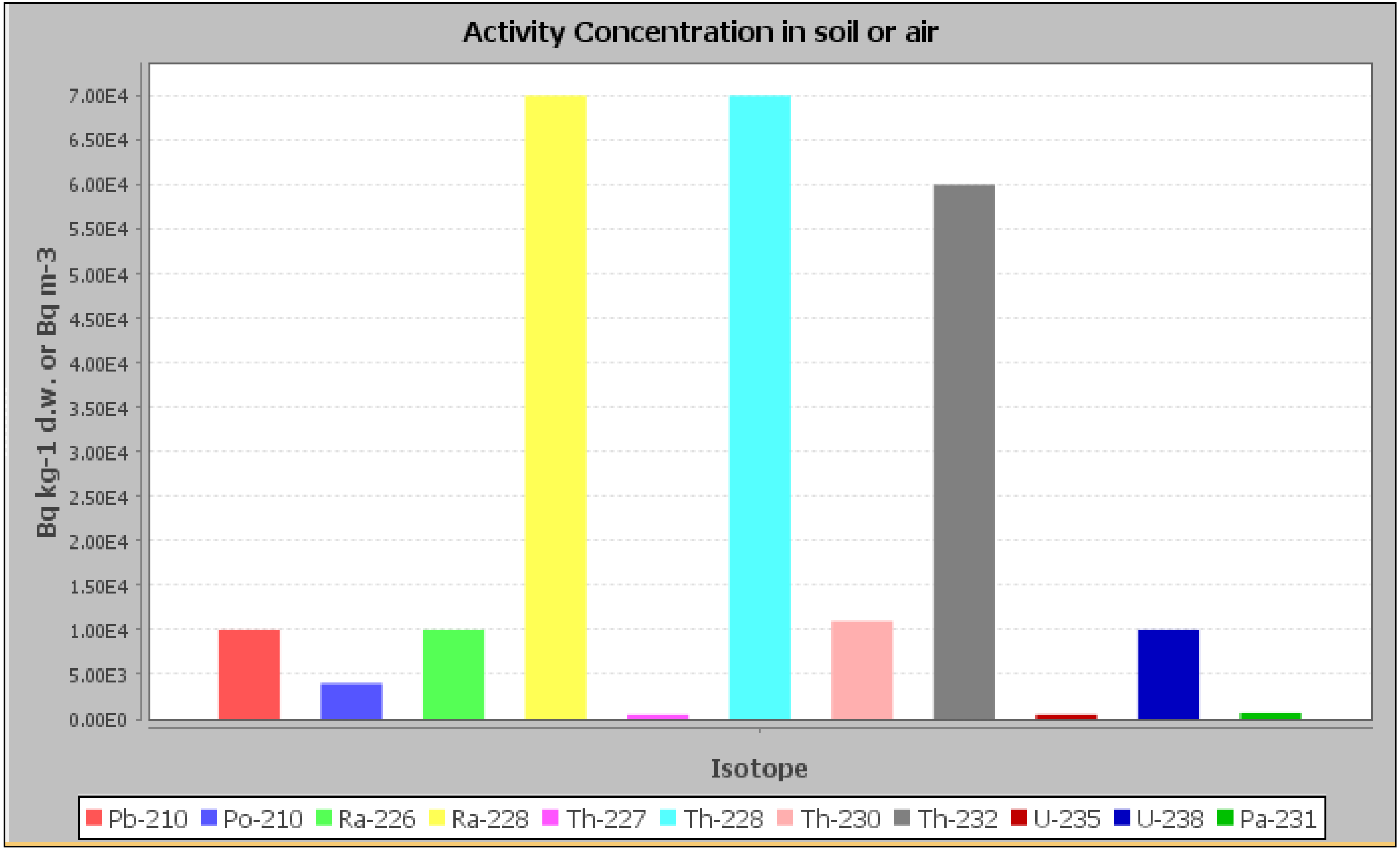
Appendix A

ERICA Assessment uranium and thorium sands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Bq kg-1 d.w. or Bq m-3
7.00E4
6.50E4
6.00E4
5.50E4
5.00E4
4.50E4
4.00E4
3.50E4
3.00E4
2.50E4
2.00E4
1.50E4
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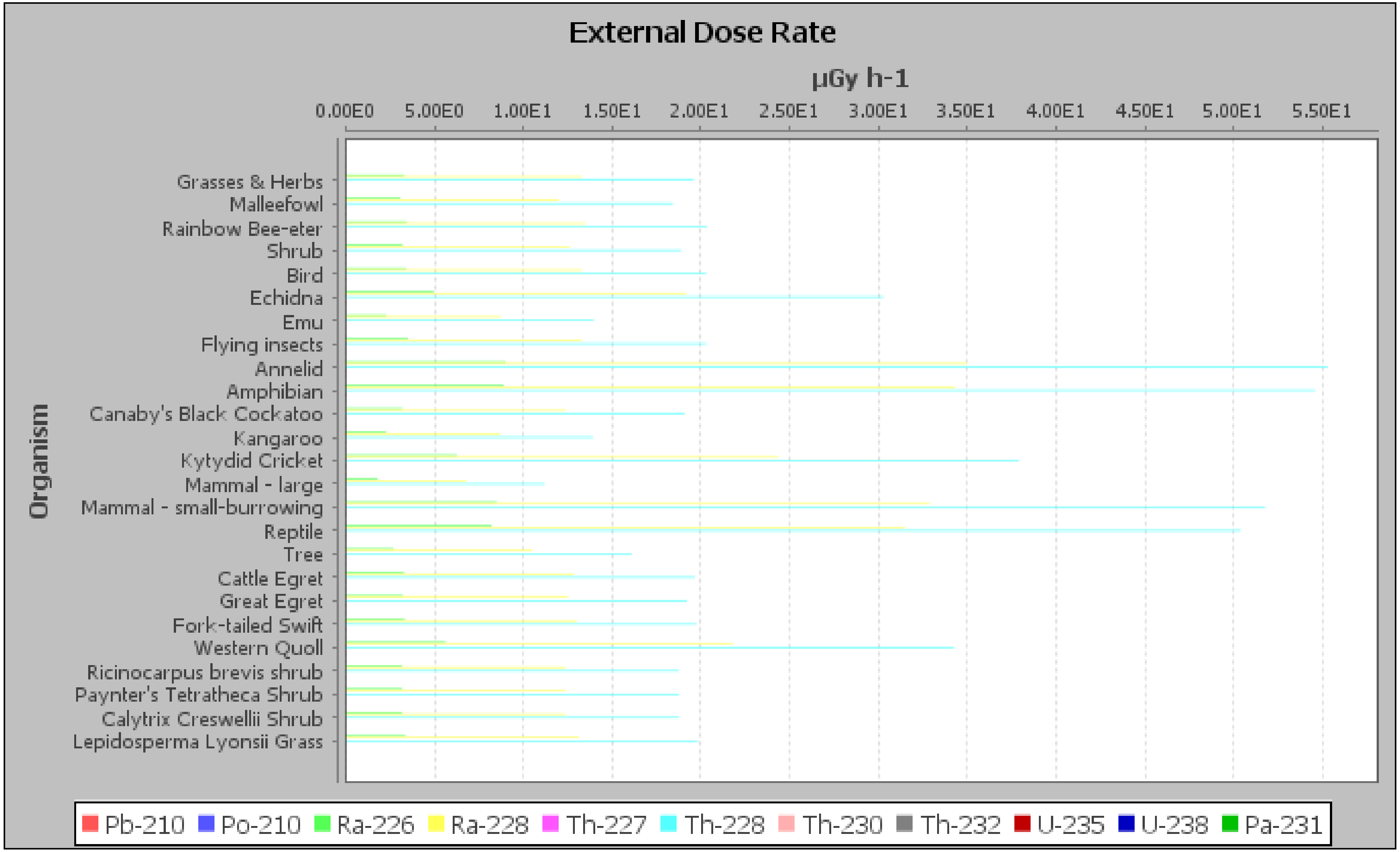
Pb-210 Po-210 Ra-226 Ra-228 Th-227 Th-228 Th-230 Th-232 U-235 U-238 Pa-231



External Dose Rate
µGy h-1
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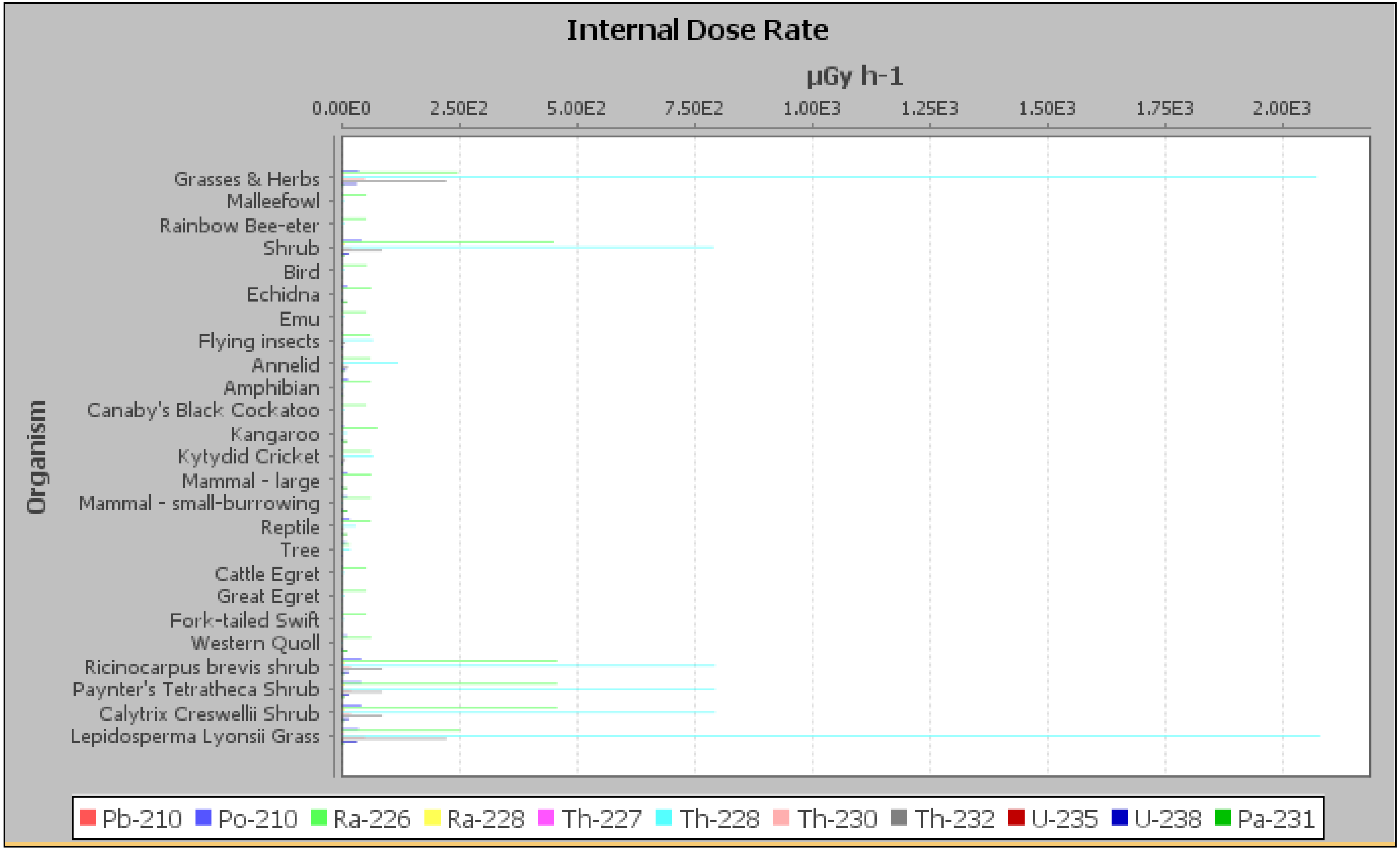
1.00E1
1.50E1
2.00E1
2.50E1
3.00E1
3.50E1
4.00E1
4.50E1
5.00E1
5.50E1
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass
Pb-210
Po-210
Ra-226
Ra-228
Th-227
Th-228
Th-230
Th-232
U-235
U-238
Pa-231


Internal Dose Rate
µGy h-1
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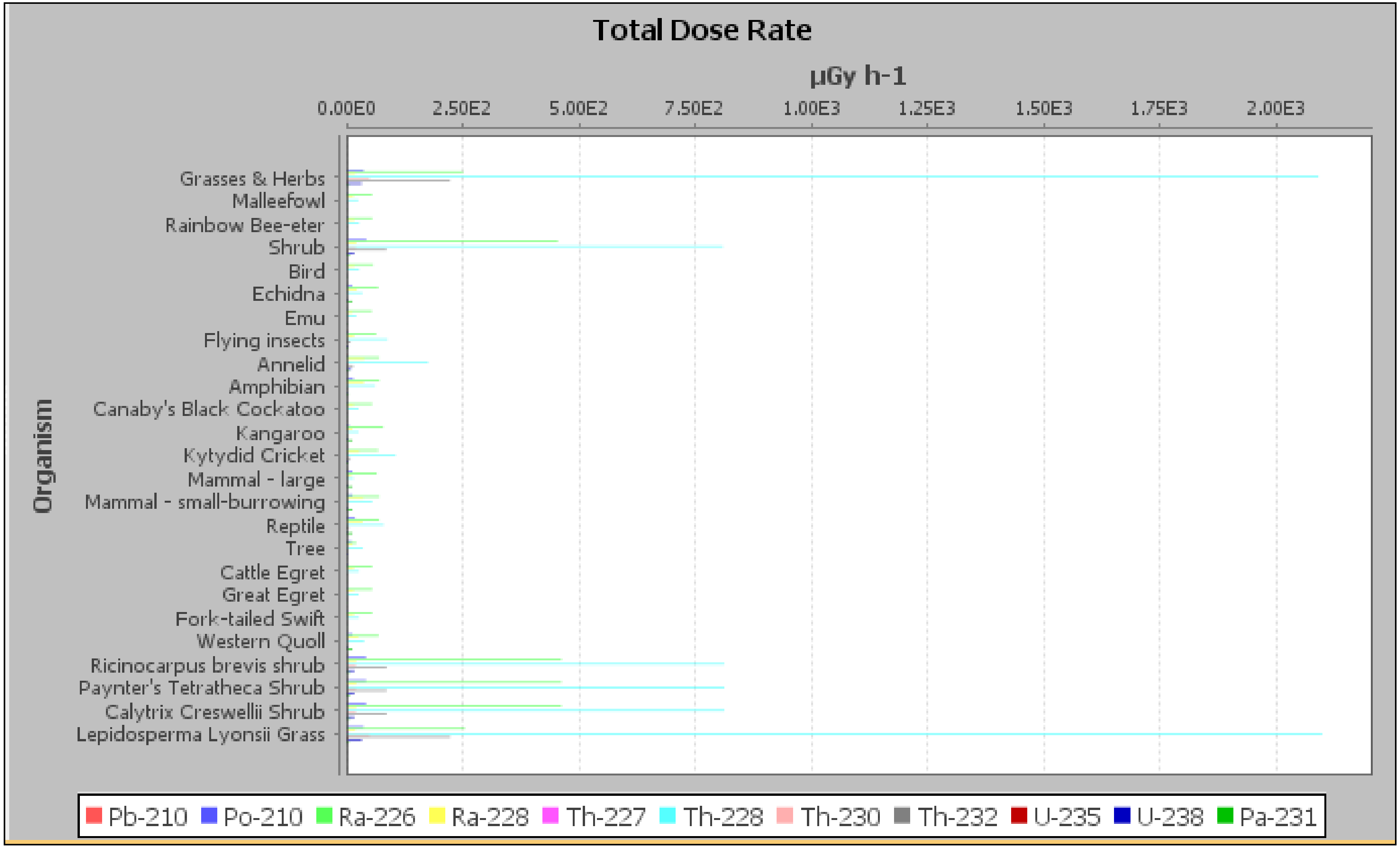
2.50E2
5.00E2
7.50E2
1.00E3
1.25E3
1.50E3
1.75E3
2.00E3
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass
Pb-210
Po-210
Ra-226
Ra-228
Th-227
Th-228
Th-230
Th-232
U-235
U-238
Pa-231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2.00E3
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass
Pb-210
Po-210
Ra-226
Ra-228
Th-227
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U-235
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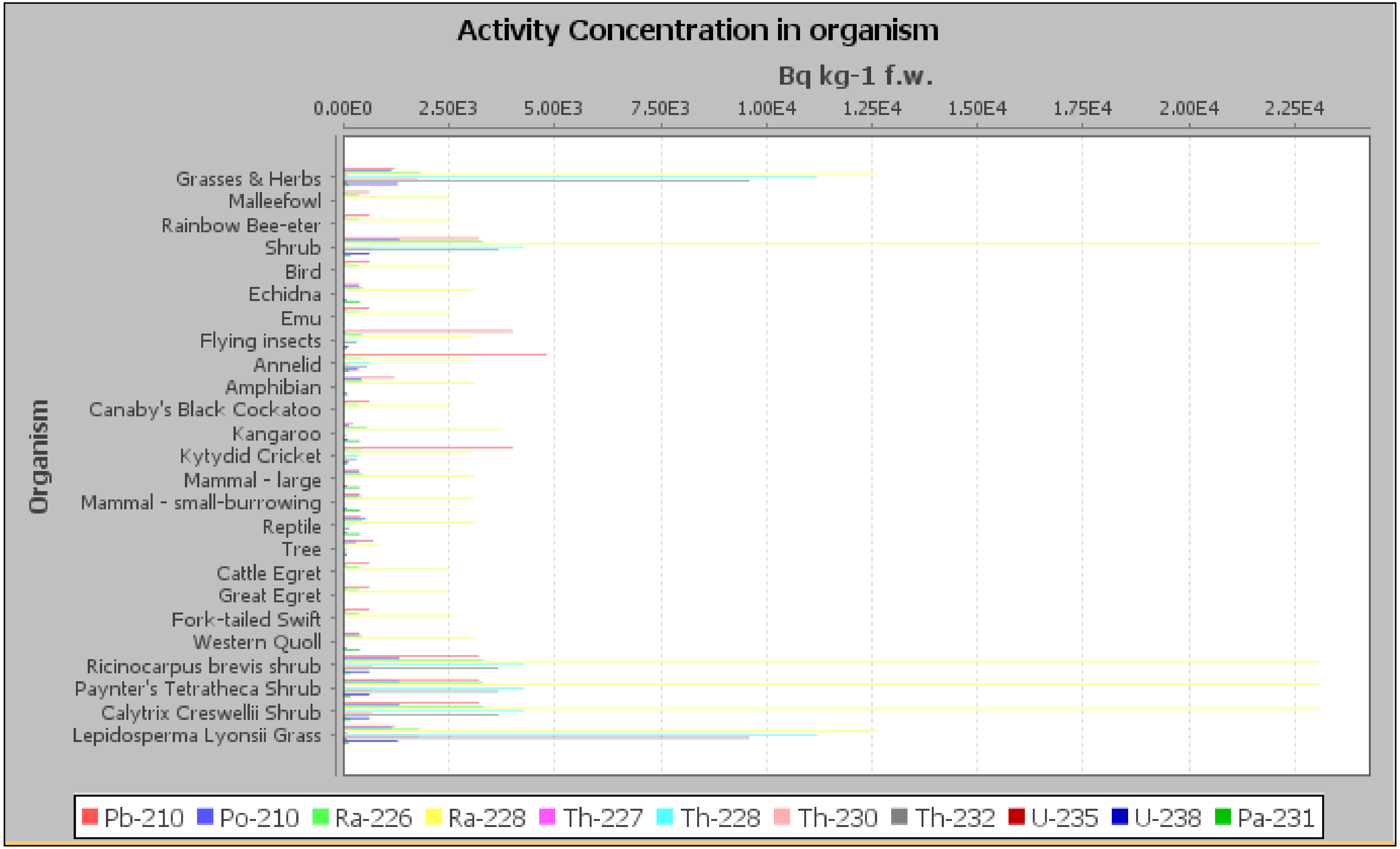
Pa-231



Activity Concentration in organism
Bq kg-1 f.w.
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5.00E3
7.50E3
1.00E4
1.25E4
1.50E4
1.75E4
2.00E4
2.25E4
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass
Pb-210
Po-210
Ra-226
Ra-228
Th-227
Th-228
Th-230
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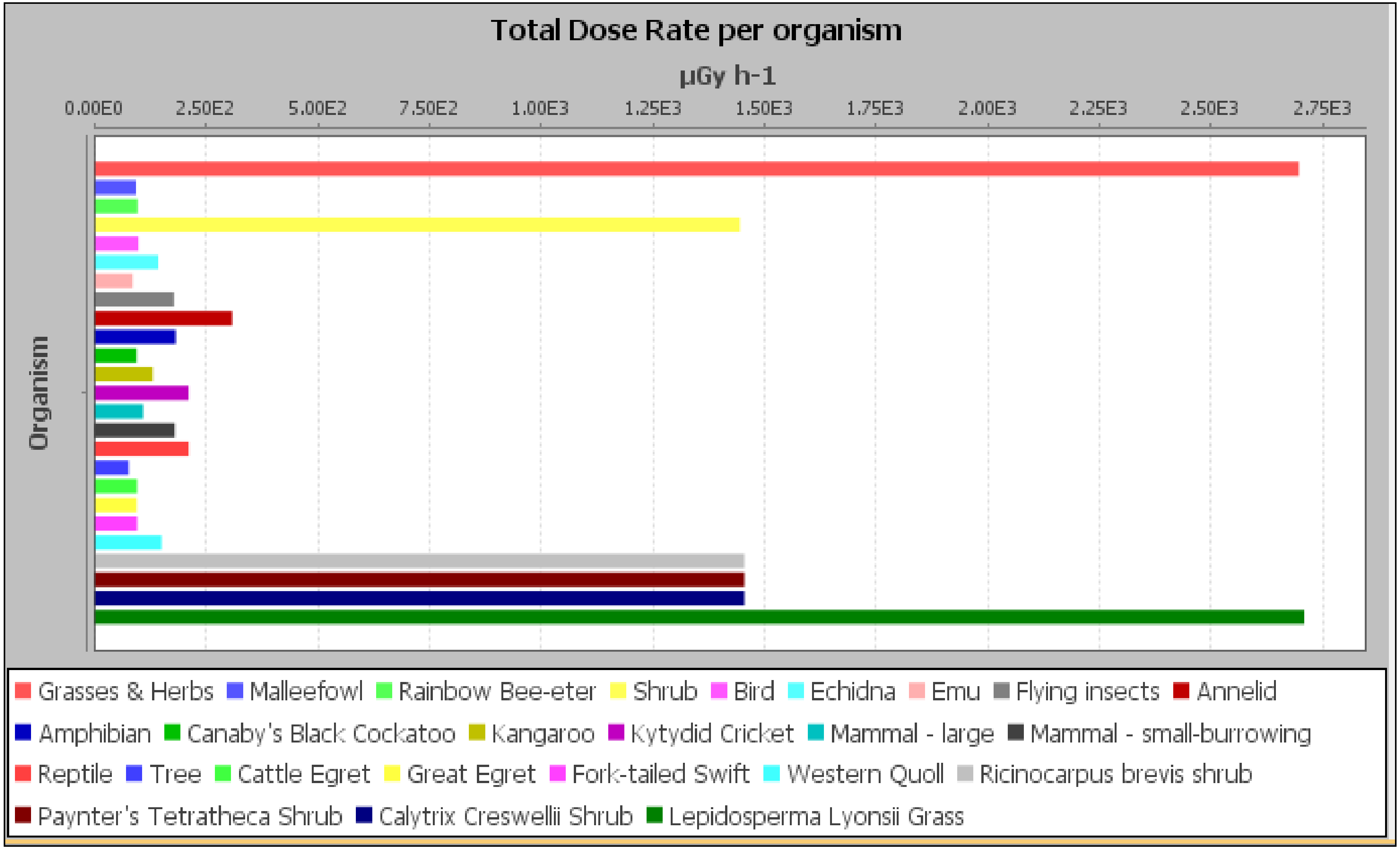
U-235
U-238
Pa-231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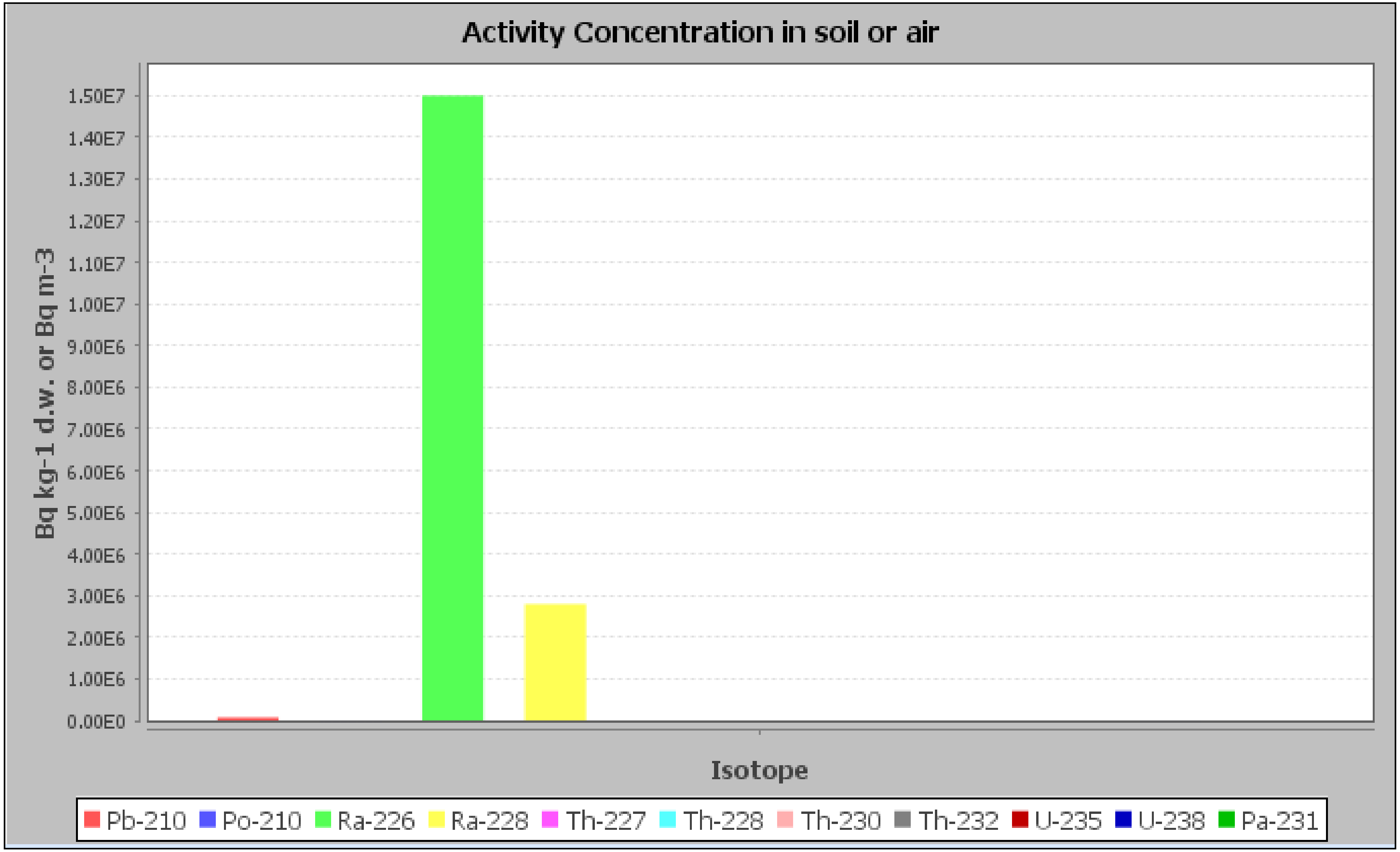
5.00E2
7.50E2
1.00E3
1.25E3
1.50E3
1.75E3
2.00E3
2.25E3
2.50E3
2.75E3
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass

Appendix B

ERICA Assessment Radium Scales


Activity Concentration in soil or air
Bq kg-1 d.w. or Bq m-3
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1.30E7
1.20E7
1.10E7
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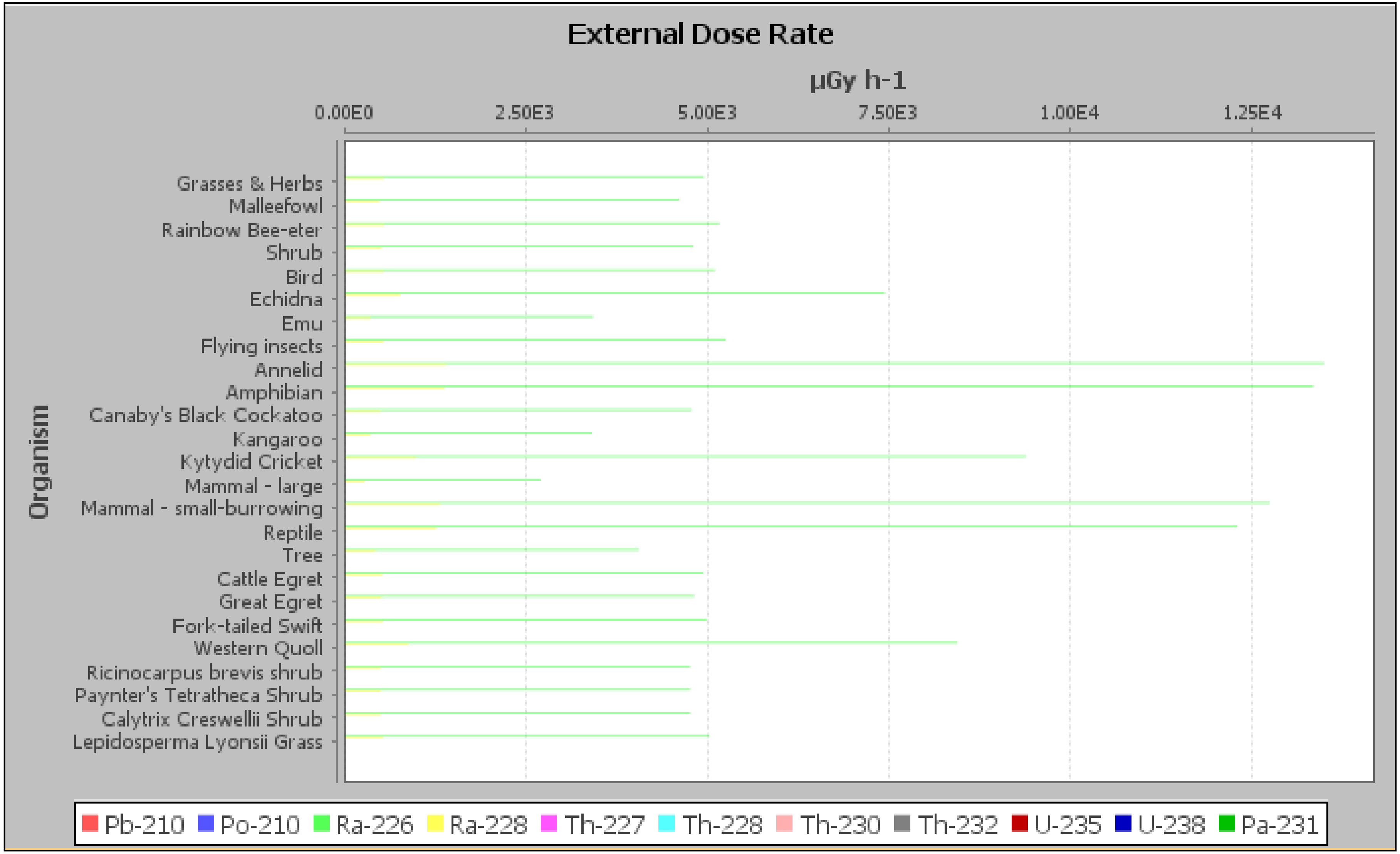
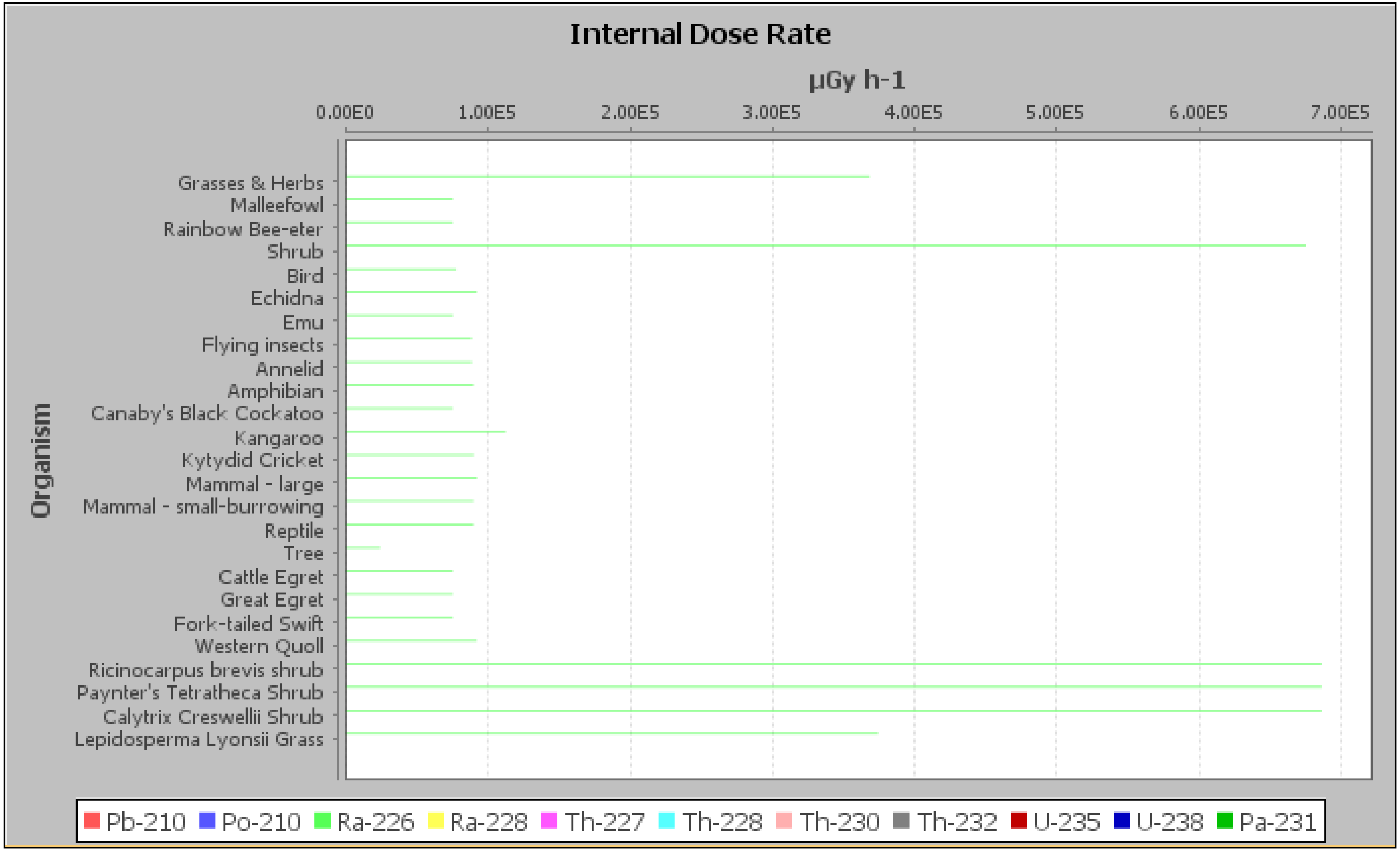
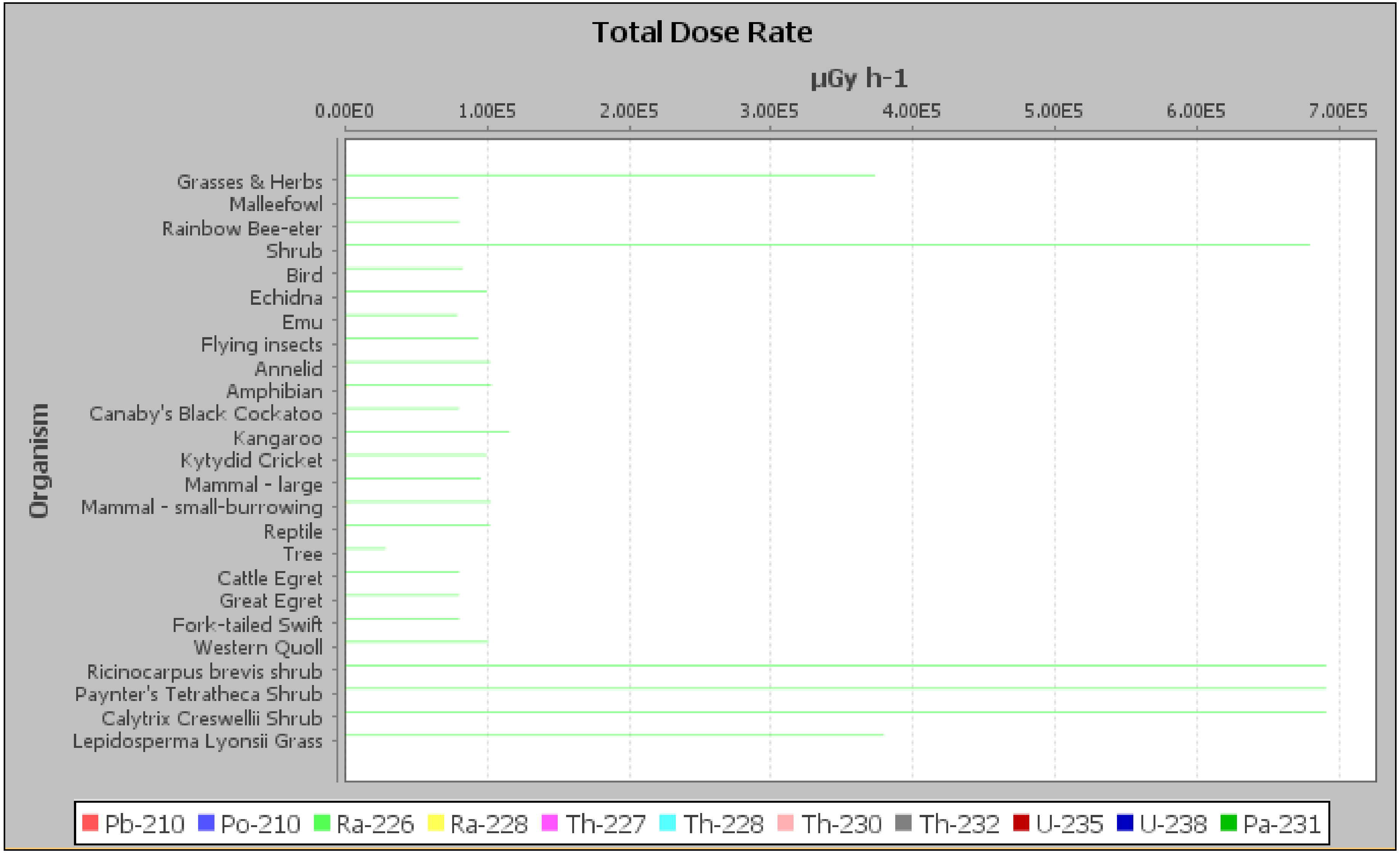
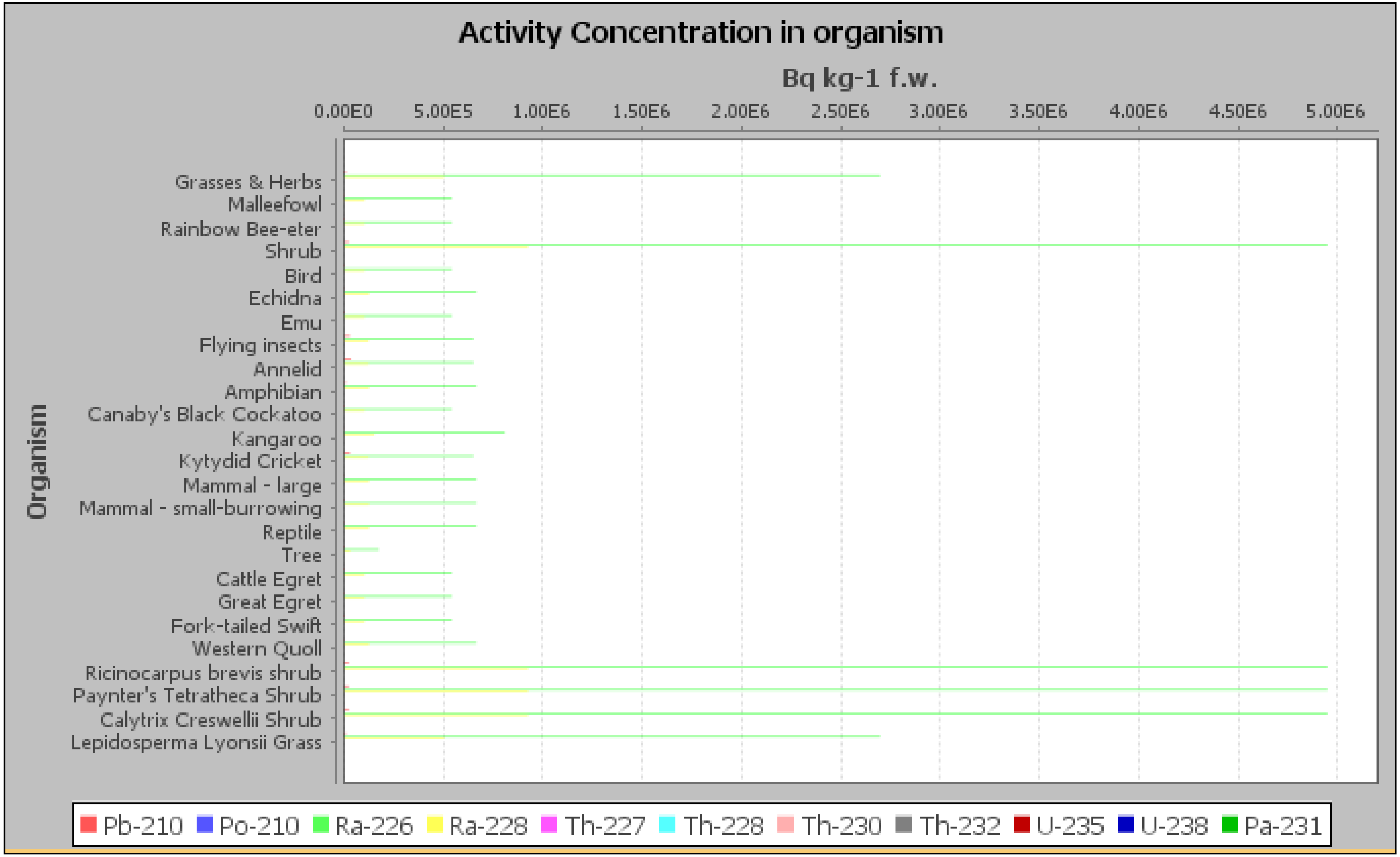
9.00E6
8.00E6
7.00E6
6.00E6
5.00E6
4.00E6
3.00E6
2.00E6
1.00E6
0.00E0
Isotope
Pb-210 Po-210 Ra-226 Ra-228 Th-227 Th-228 Th-230 Th-232 U-235 U-238 Pa-231

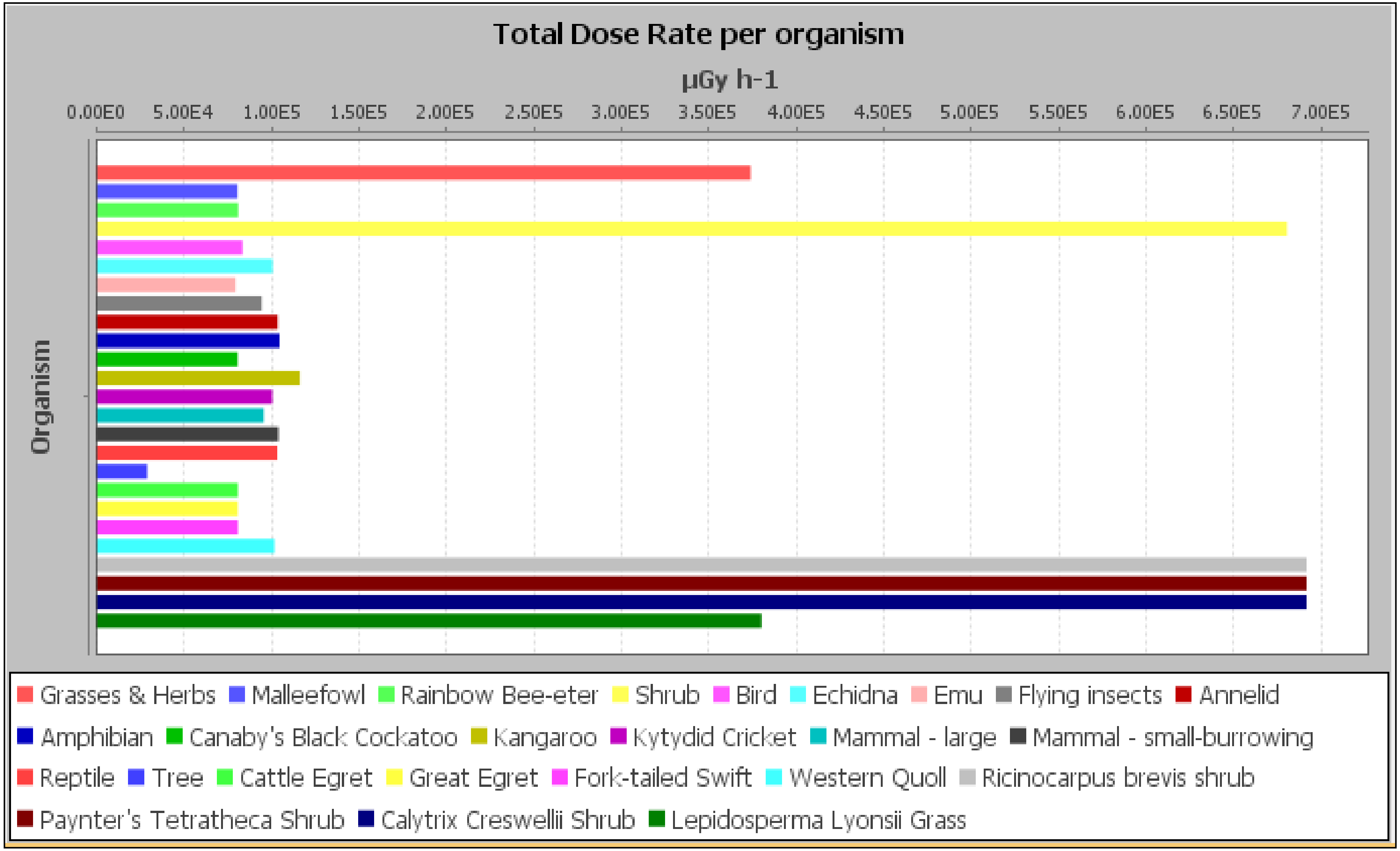

External Dose Rate
µGy h-1
0.00E0
2.50E3
5.00E3
7.50E3
1.00E4
1.25E4
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass
Pb-210
Po-210
Ra-226
Ra-228
Th-227
Th-228
Th-230
Th-232
U-235
U-238
Pa-231


Internal Dose Rate
µGy h-1
0.00E0
1.00E5
2.00E5
3.00E5
4.00E5
5.00E5
6.00E5
7.00E5
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass
Pb-210
Po-210
Ra-226
Ra-228
Th-227
Th-228
Th-230
Th-232
U-235
U-238
Pa-231



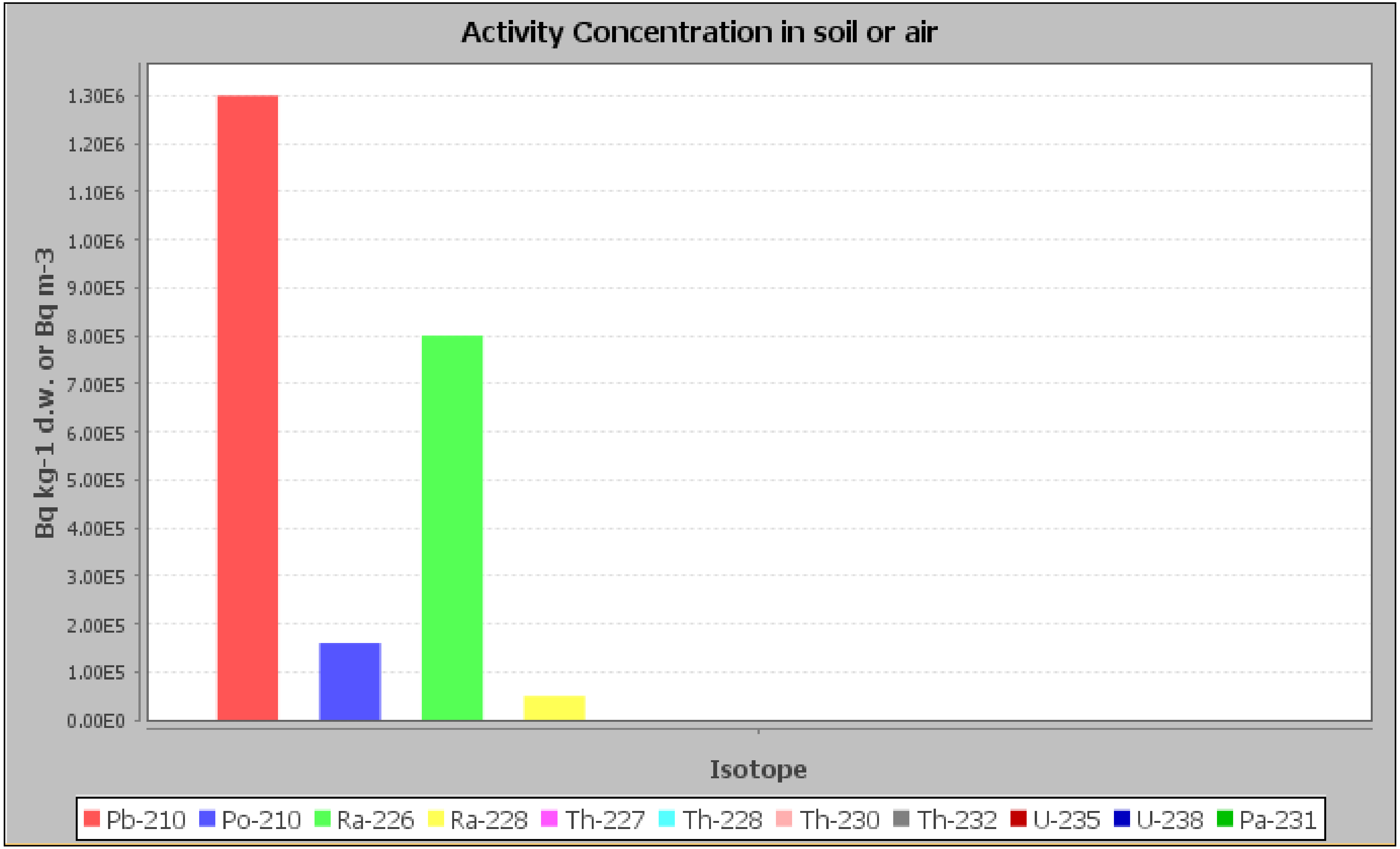
Total Dose Rate
µGy h-1
0.00E0
1.00E5
2.00E5
3.00E5
4.00E5
5.00E5
6.00E5
7.00E5
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass
Pb-210
Po-210
Ra-226
Ra-228
Th-227
Th-228
Th-230
Th-232
U-235
U-238
Pa-231

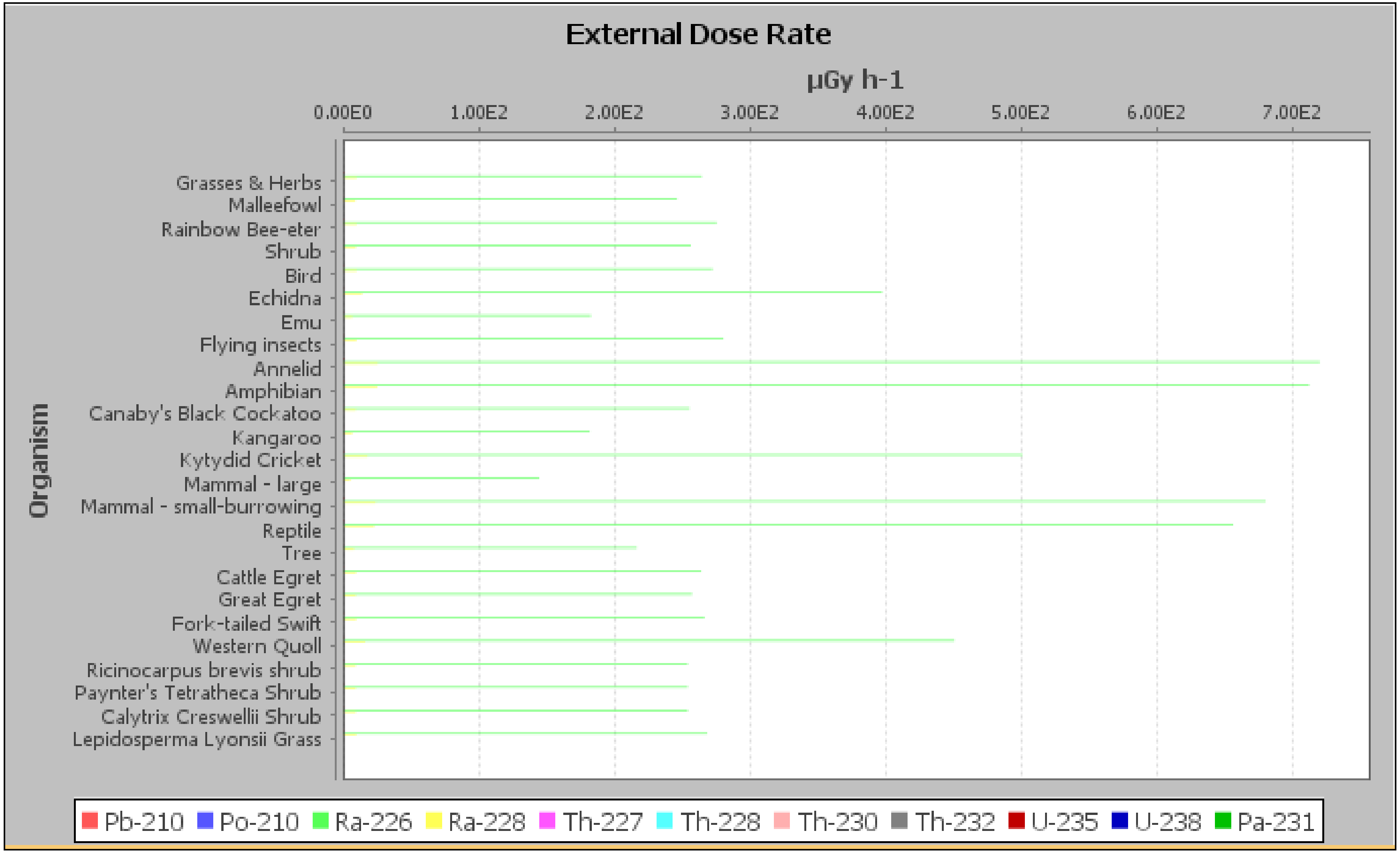

Activity Concentration in organism
Bq kg-1 f.w.
0.00E0
5.00E5
1.00E6
1.50E6
2.00E6
2.50E6
3.00E6
3.50E6
4.00E6
4.50E6
5.00E6
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass
Pb-210
Po-210
Ra-226
Ra-228
Th-227
Th-228
Th-230
Th-232
U-235
U-238
Pa-231


Total Dose Rate per organism
µGy h-1
0.00E0
5.00E4
1.00E5
1.50E5
2.00E5
2.50E5
3.00E5
3.50E5
4.00E5
4.50E5
5.00E5
5.50E5
6.00E5
6.50E5
7.00E5
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass

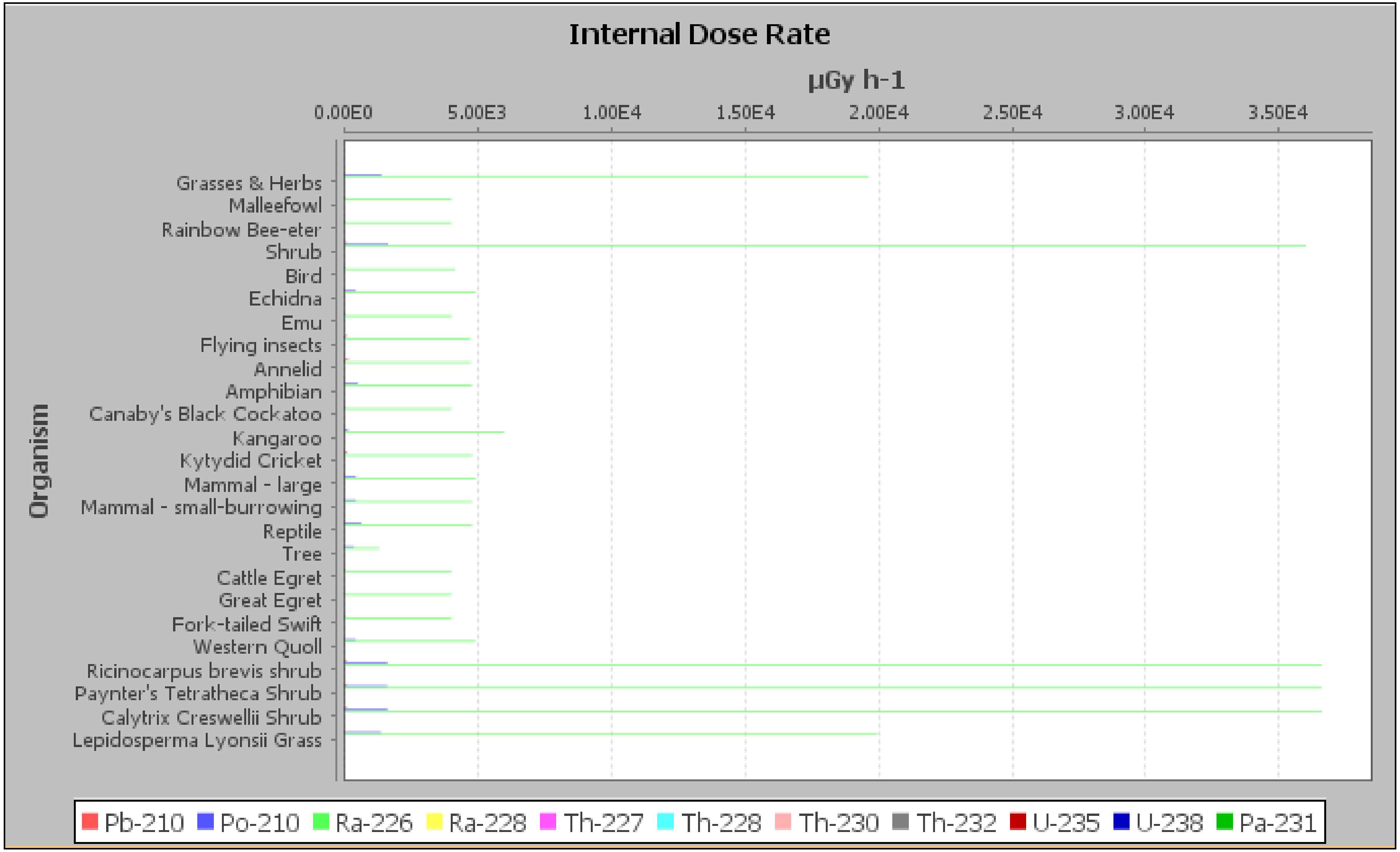
Appendix C

ERICA Assessment Radium Sludge

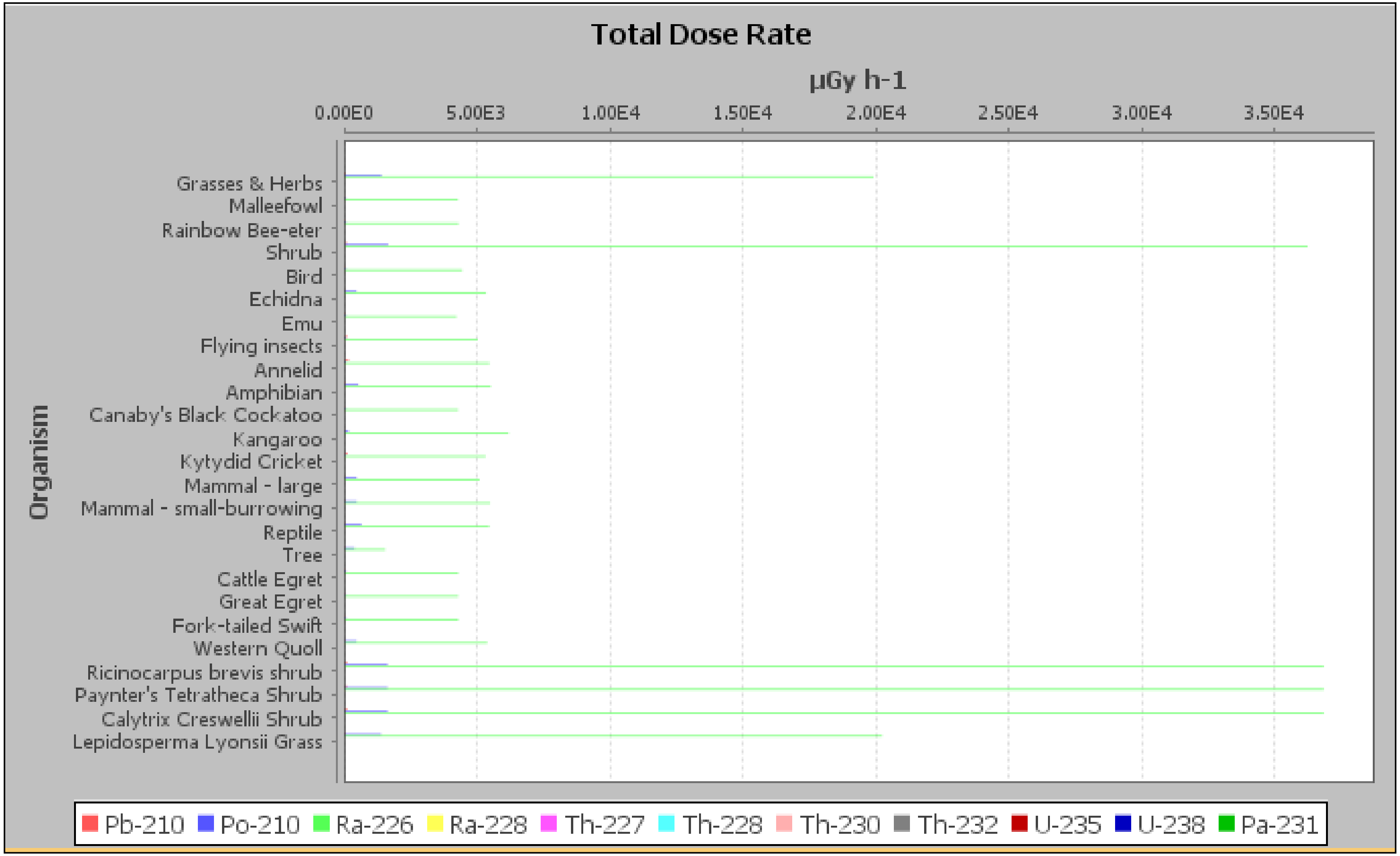

Activity Concentration in soil or air
Bq kg-1 d.w. or Bq m-3
1.30E6
1.20E6
1.10E6
1.00E6
9.00E5
8.00E5
7.00E5
6.00E5
5.00E5
4.00E5
3.00E5
2.00E5
1.00E5
0.00E0
Isotope
Pb-210
Po-210
Ra-226
Ra-228
Th-227
Th-228
Th-230
Th-232
U-235
U-238
Pa-231

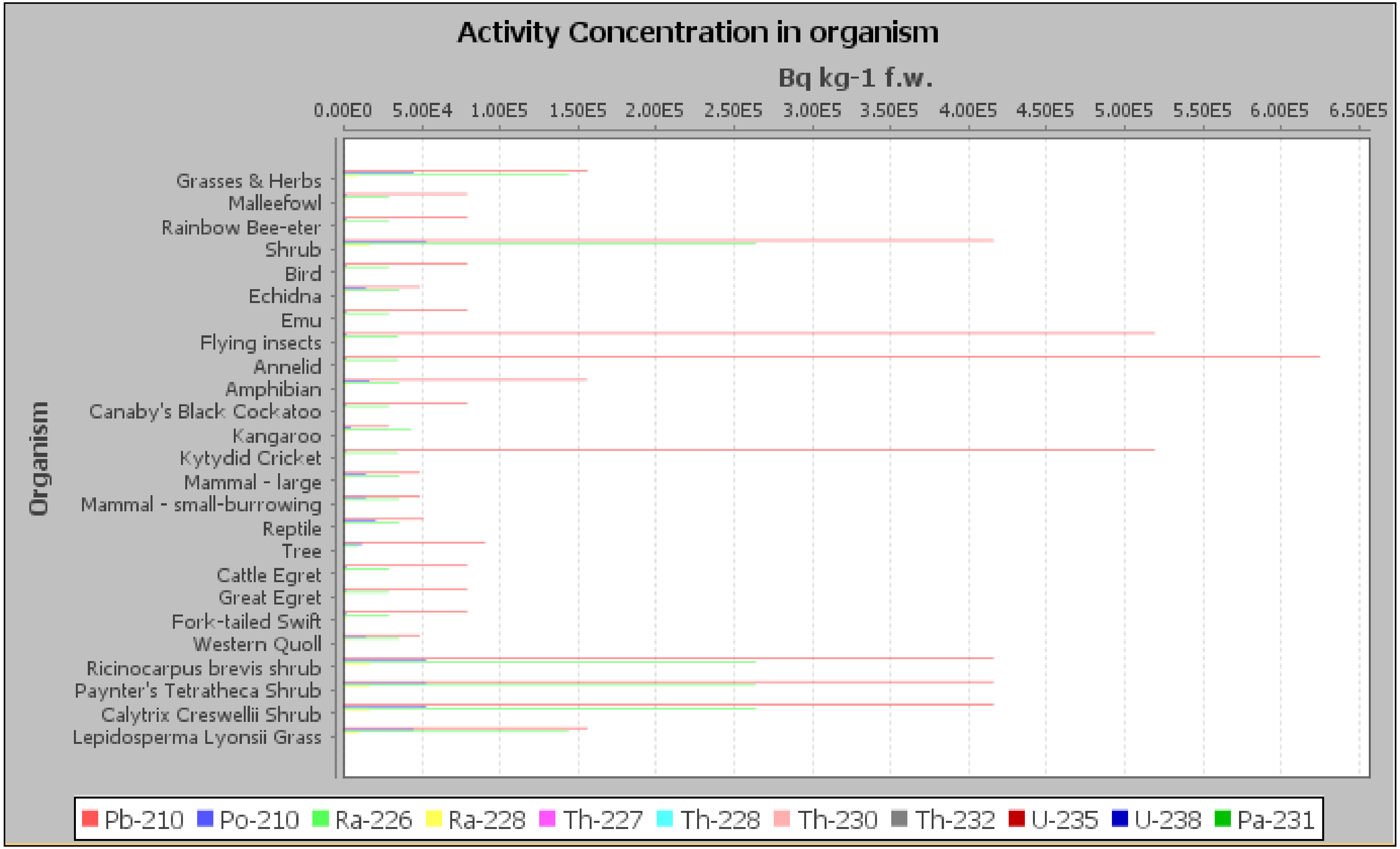


External Dose Rate
µGy h-1
0.00E0
1.00E2
2.00E2
3.00E2
4.00E2
5.00E2
6.00E2
7.00E2
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass
Pb-210
Po-210
Ra-226
Ra-228
Th-227
Th-228
Th-230
Th-232
U-235
U-238
Pa-231



Internal Dose Rate
µGy h-1
0.00E0
5.00E3
1.00E4
1.50E4
2.00E4
2.50E4
3.00E4
3.50E4
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass
Pb-210
Po-210
Ra-226
Ra-228
Th-227
Th-228
Th-230
Th-232
U-235
U-238
Pa-231


Total Dose Rate
µGy h-1
0.00E0
5.00E3
1.00E4
1.50E4
2.00E4
2.50E4
3.00E4
3.50E4
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass
Pb-210
Po-210
Ra-226
Ra-228
Th-227
Th-228
Th-230
Th-232
U-235
U-238
Pa-231


Activity Concentration in organism
Bq kg-1 f.w.
0.00E0
5.00E4
1.00E5
1.50E5
2.00E5
2.50E5
3.00E5
3.50E5
4.00E5
4.50E5
5.00E5
5.50E5
6.00E5
6.50E5
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass
Pb-210
Po-210
Ra-226
Ra-228
Th-227
Th-228
Th-230
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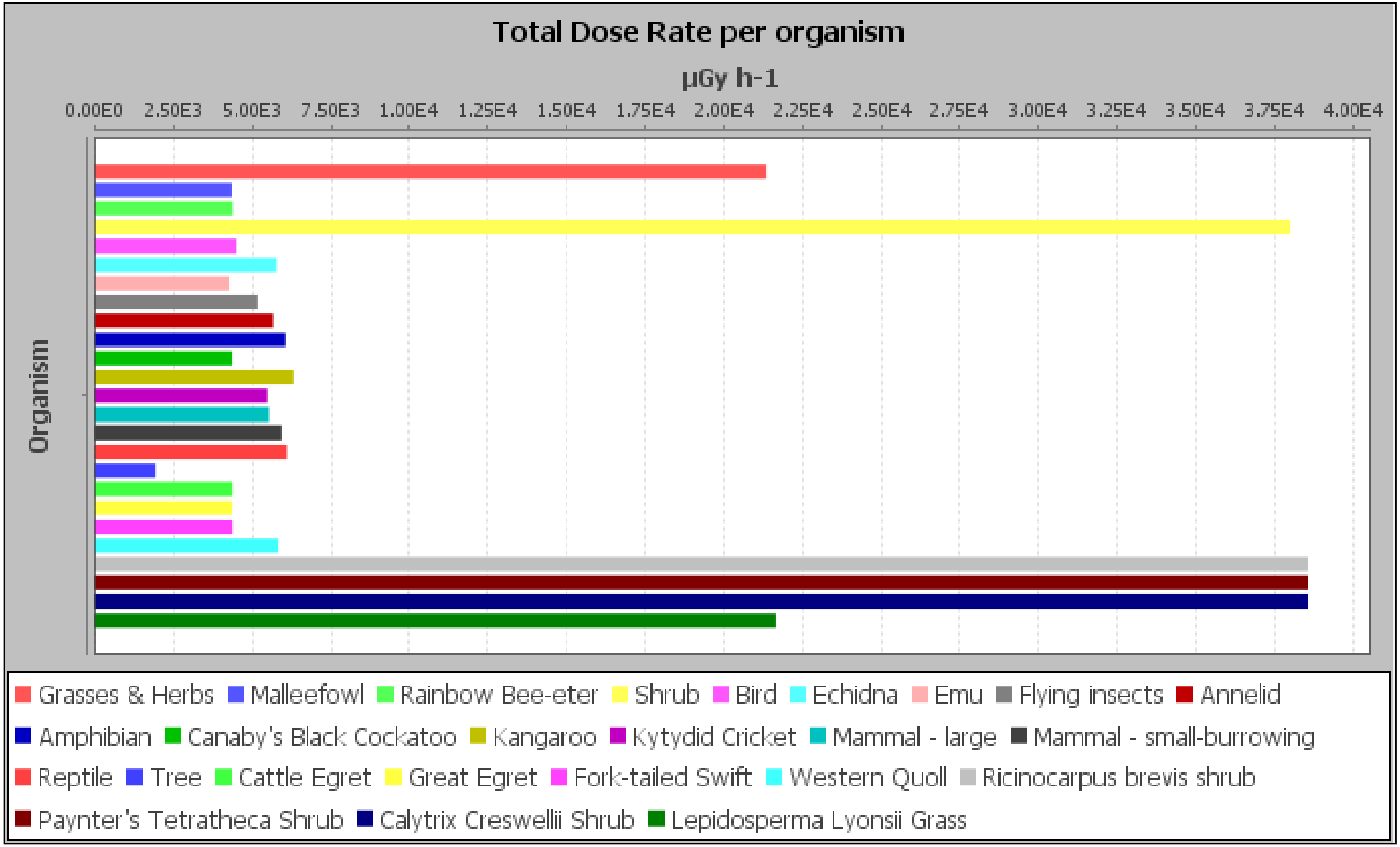
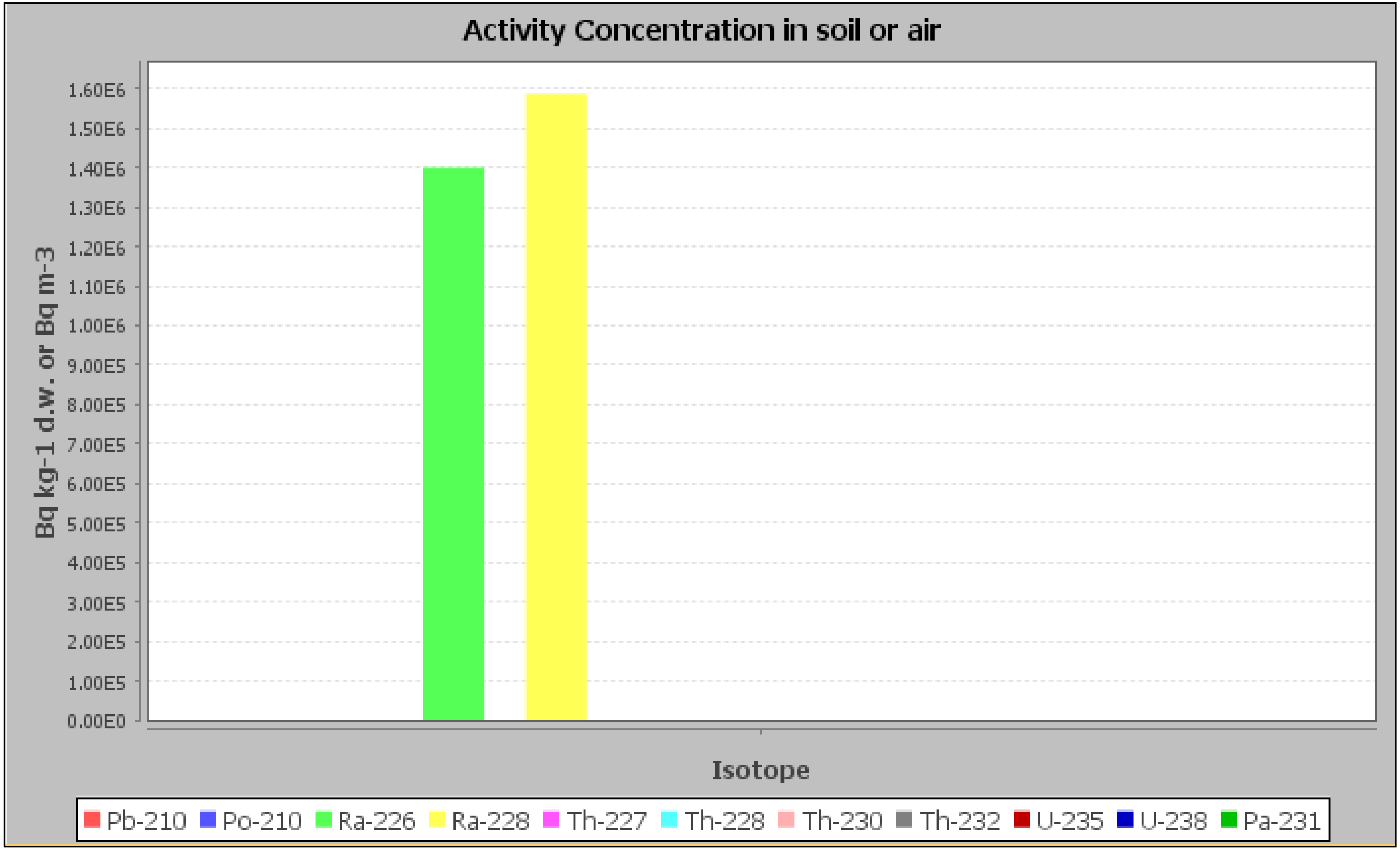
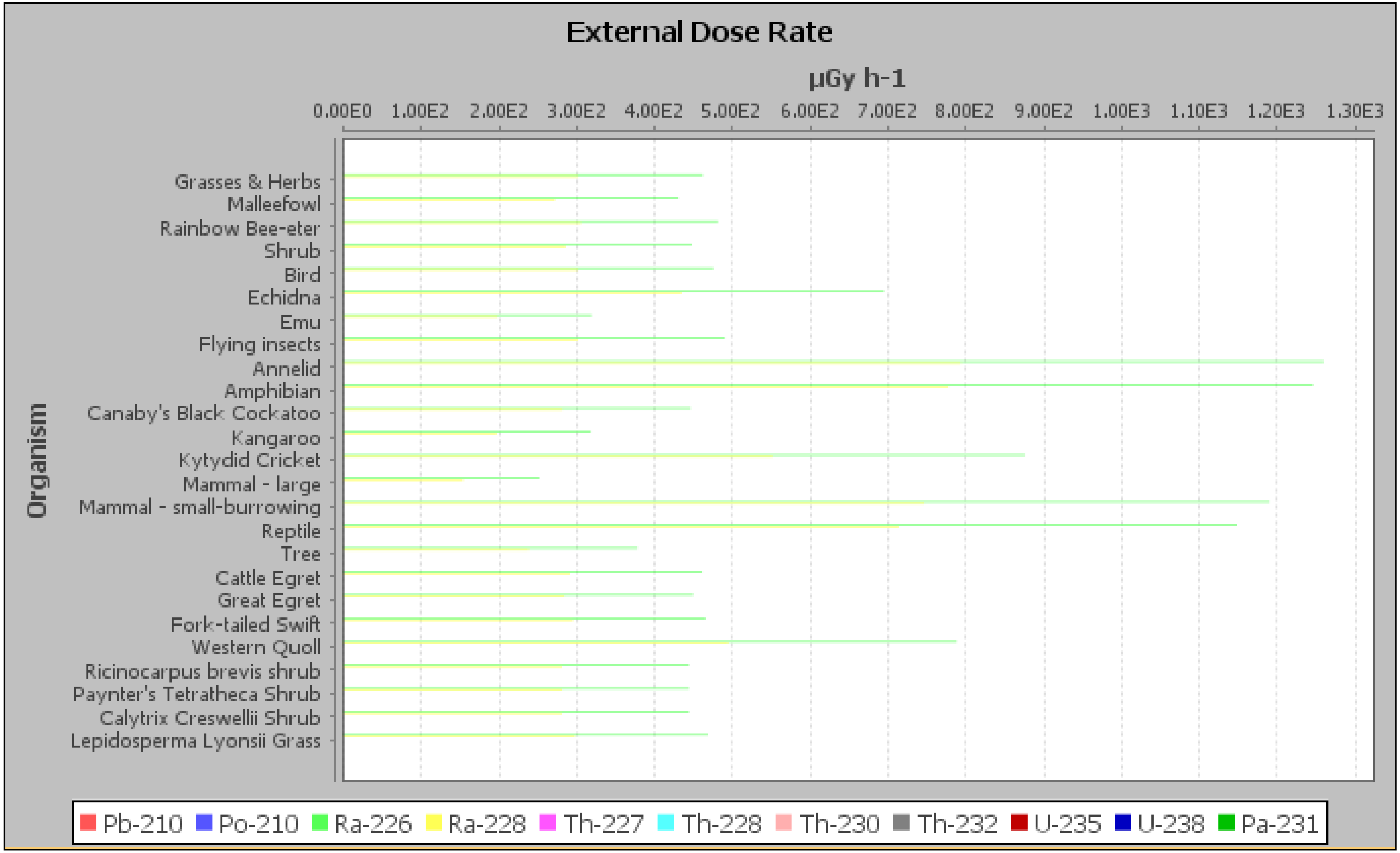
U-235
U-238
Pa-231

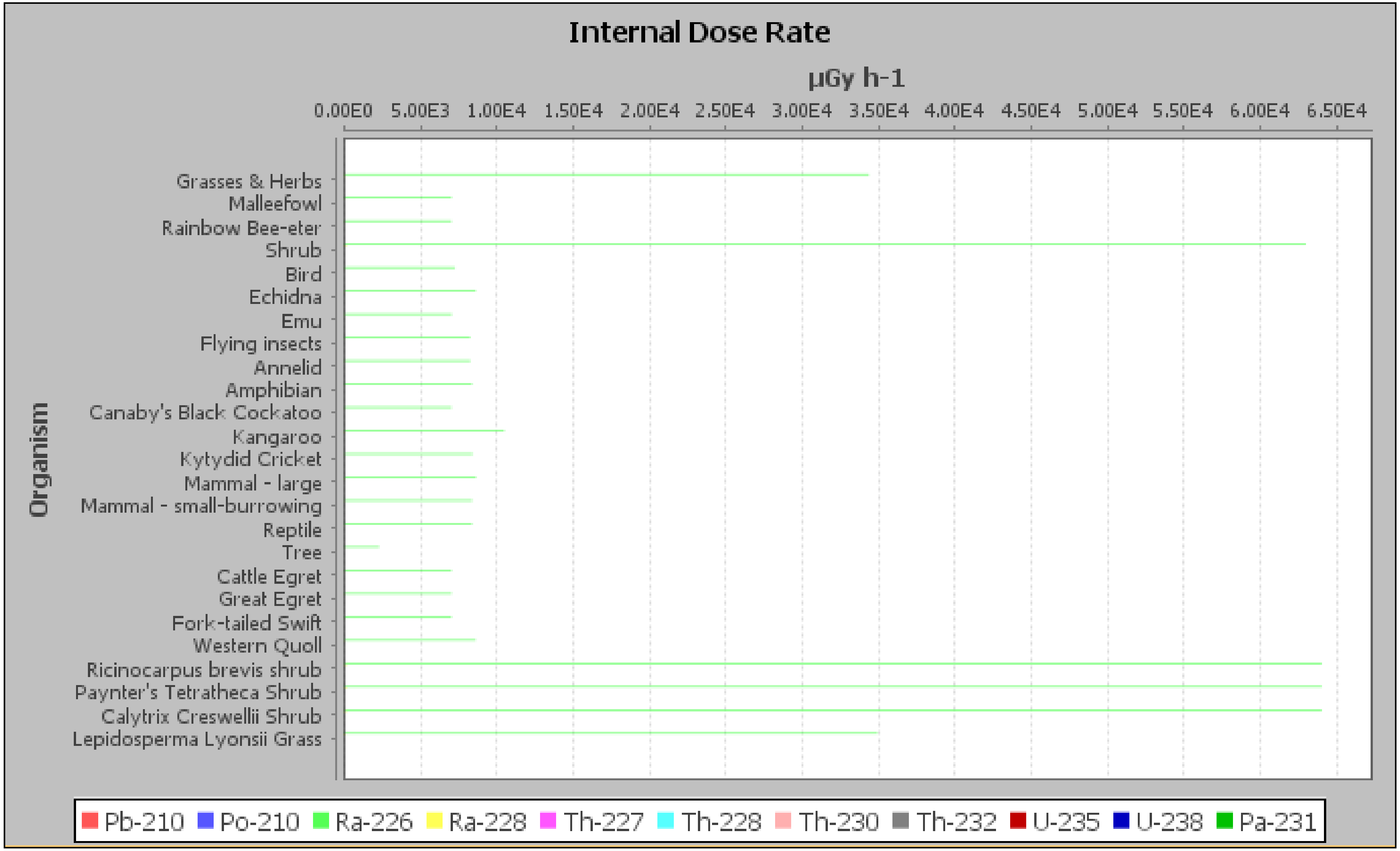

Total Dose Rate per organism
µGy h-1
0.00E0
2.50E3
5.00E3
7.50E3
1.00E4
1.25E4
1.50E4
1.75E4
2.00E4
2.25E4
2.50E4
2.75E4
3.00E4
3.25E4
3.50E4
3.75E4
4.00E4
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass

Appendix D

ERICA Assessment Oil and Gas Industry


Activity Concentration in soil or air
Bq kg-1 d.w. or Bq m-3
1.60E6
1.50E6
1.40E6
1.30E6
1.20E6
1.10E6
1.00E6
9.00E5
8.00E5
7.00E5
6.00E5
5.00E5
4.00E5
3.00E5
2.00E5
1.00E5
0.00E0
Isotope
Pb-210 Po-210 Ra-226 Ra-228 Th-227 Th-228 Th-230 Th-232 U-235 U-238 Pa-231


External Dose Rate
µGy h-1
0.00E0
1.00E2
2.00E2
3.00E2
4.00E2
5.00E2
6.00E2
7.00E2
8.00E2
9.00E2
1.00E3
1.10E3
1.20E3
1.30E3
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass
Pb-210
Po-210
Ra-226
Ra-228
Th-227
Th-228
Th-230
Th-232
U-235
U-238
Pa-231


Internal Dose Rate
µGy h-1
0.00E0
5.00E3
1.00E4
1.50E4
2.00E4
2.50E4
3.00E4
3.50E4
4.00E4
4.50E4
5.00E4
5.50E4
6.00E4
6.50E4
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass
Pb-210
Po-210
Ra-226
Ra-228
Th-227
Th-228
Th-230
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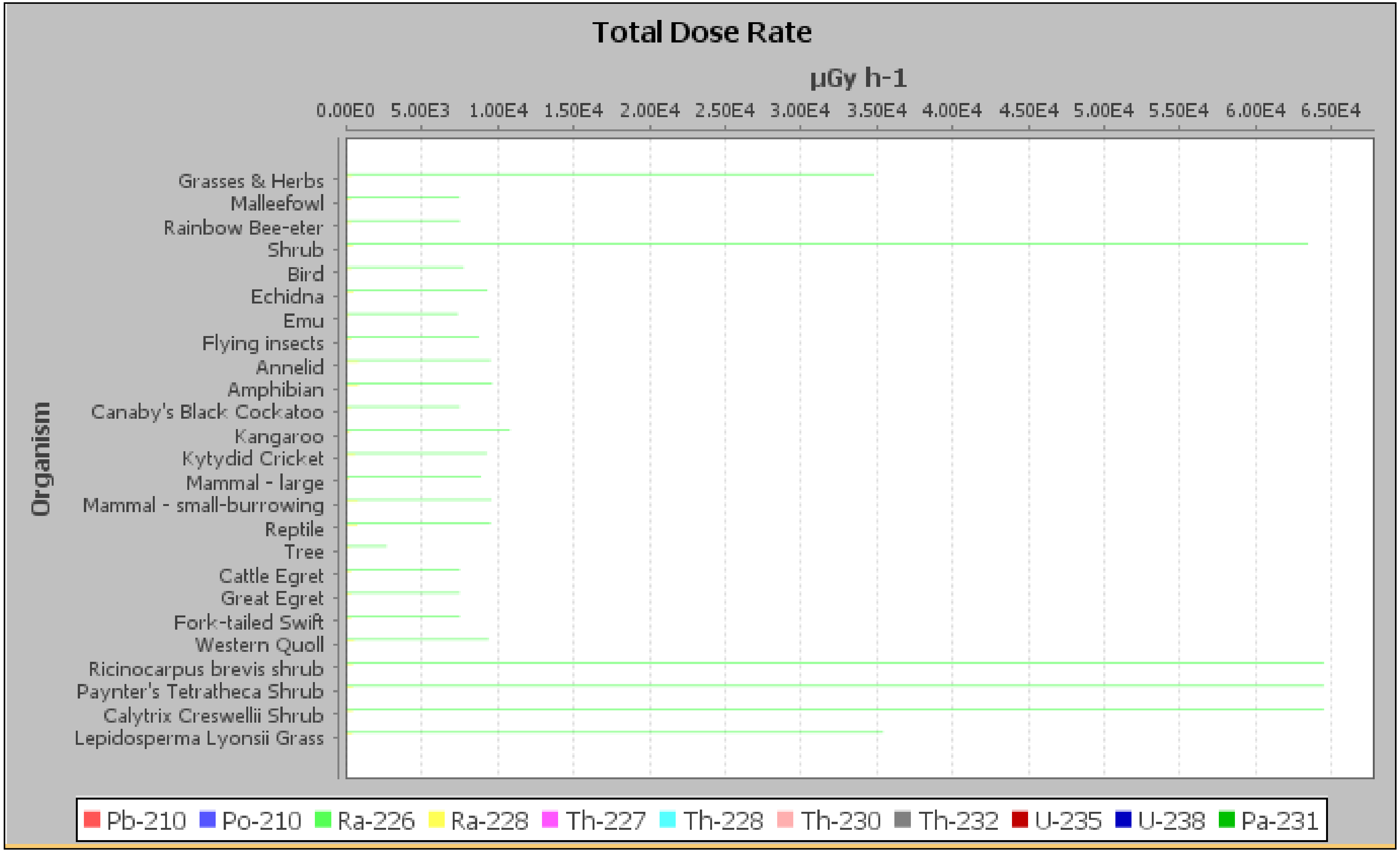
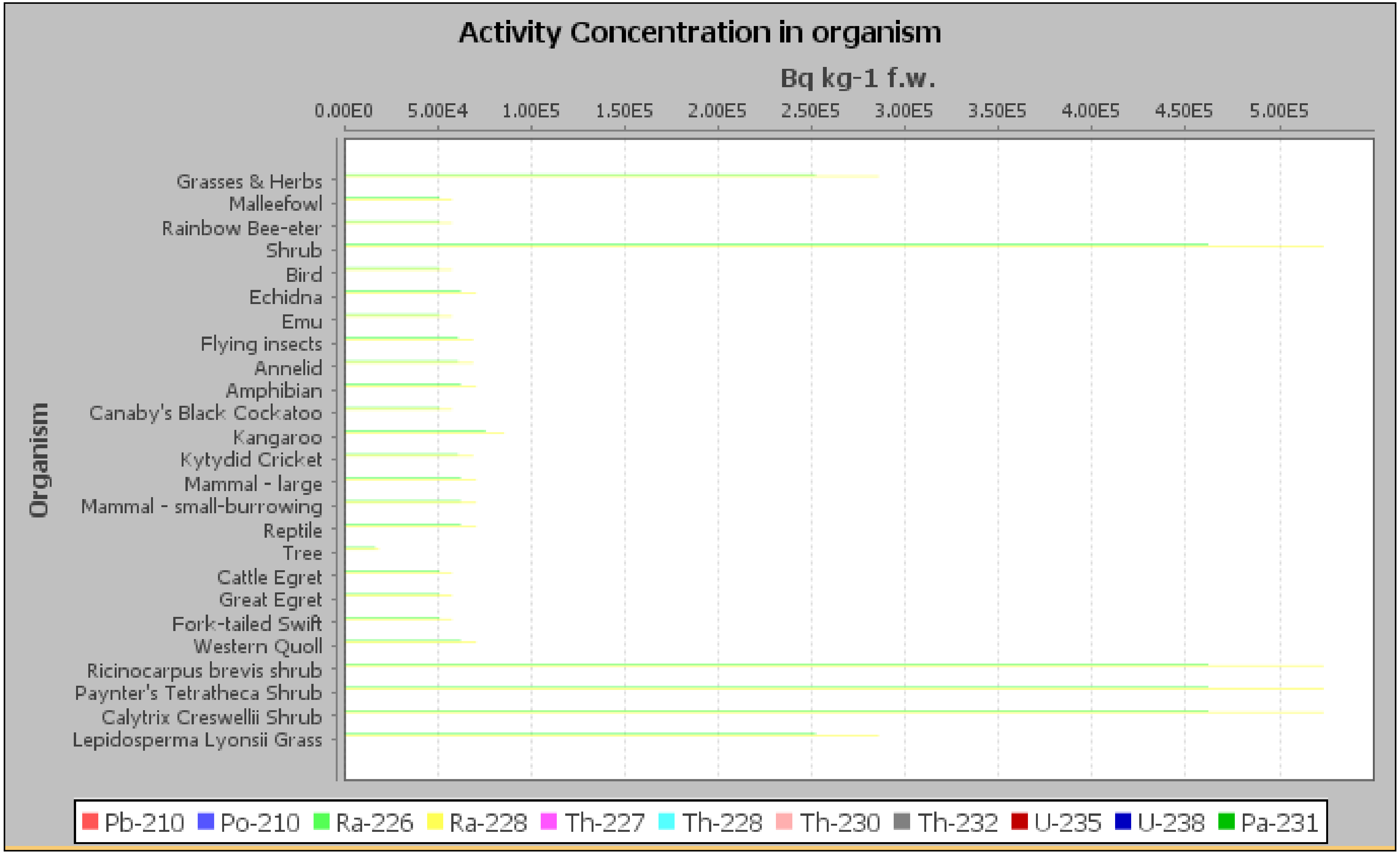
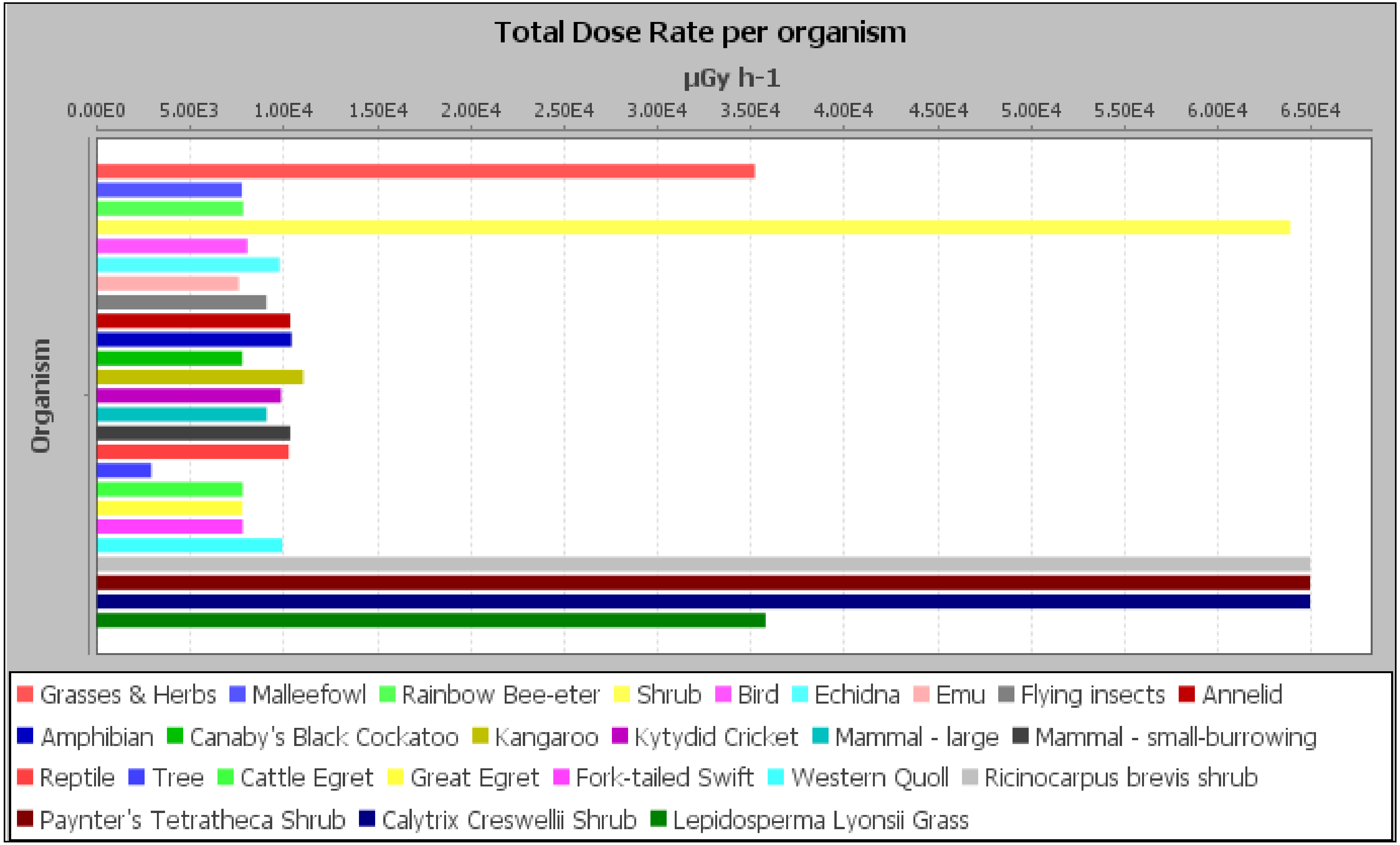
U-235
U-238
Pa-231


Total Dose Rate
µGy h-1
0.00E0 5.00E3 1.00E4 1.50E4 2.00E4 2.50E4 3.00E4 3.50E4 4.00E4 4.50E4 5.00E4 5.50E4 6.00E4 6.50E4
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass
Pb-210 Po-210 Ra-226 Ra-228 Th-227 Th-228 Th-230 Th-232 U-235 U-238 Pa-231

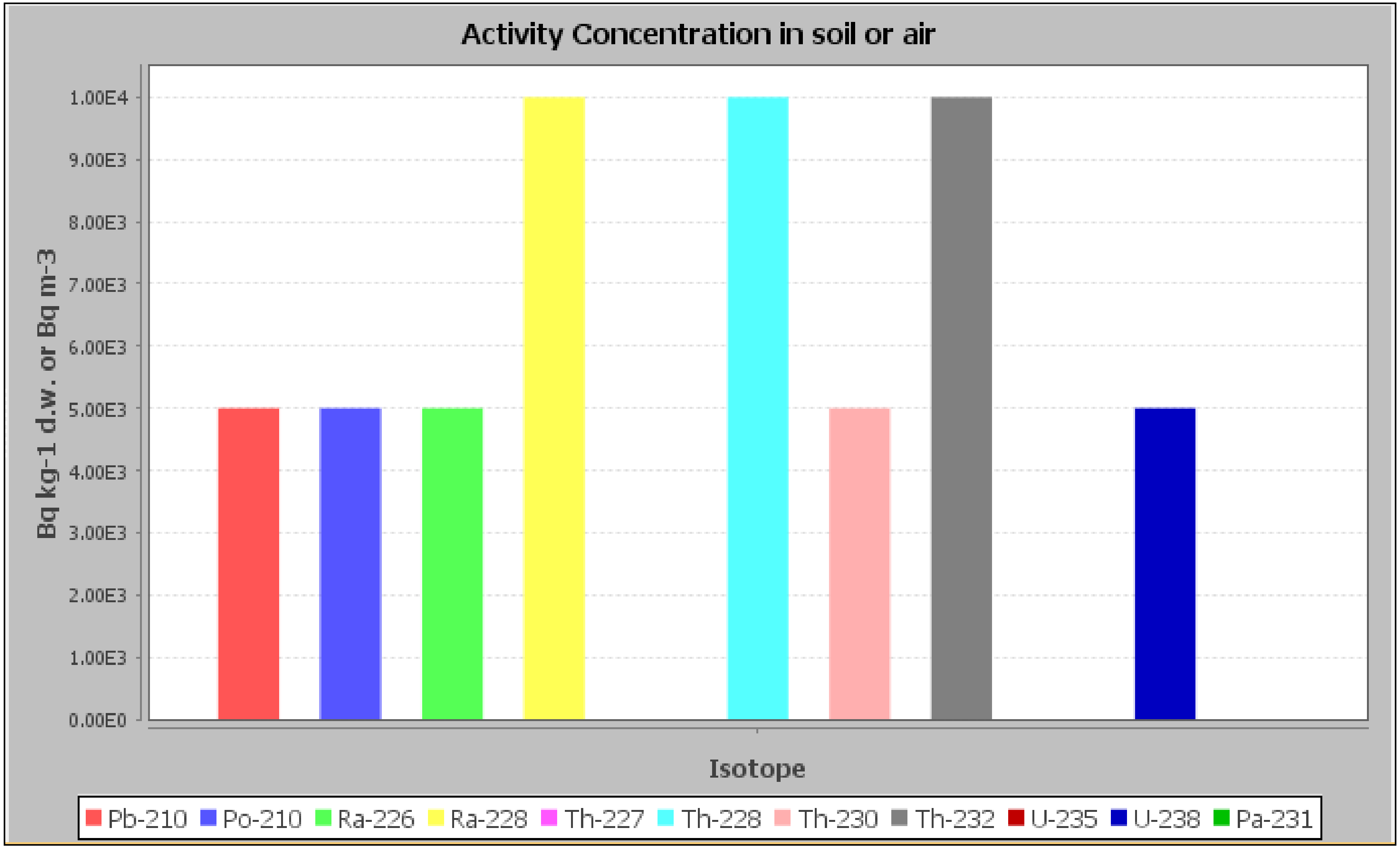


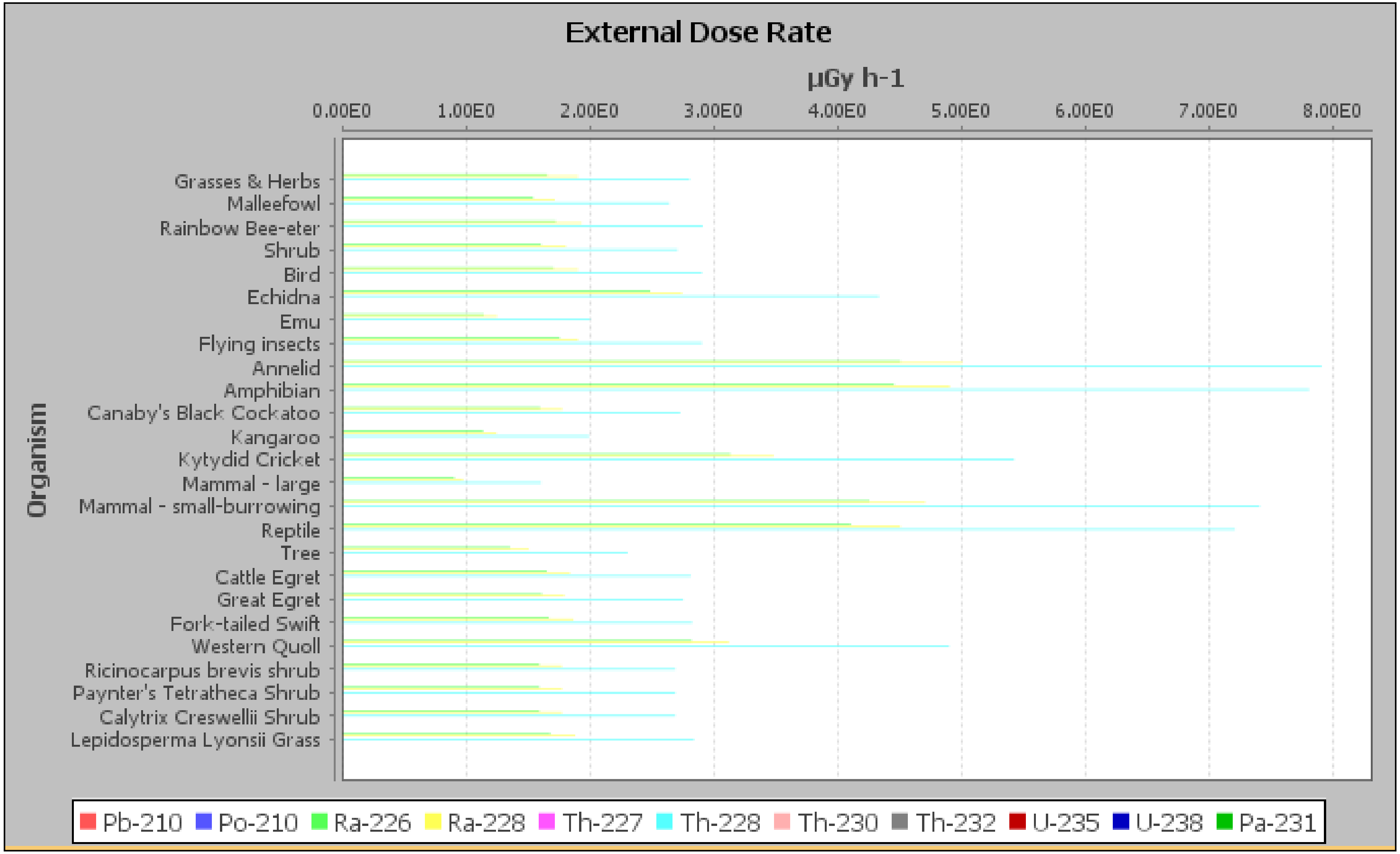
Activity Concentration in organism
Bq kg-1 f.w.
0.00E0
5.00E4
1.00E5
1.50E5
2.00E5
2.50E5
3.00E5
3.50E5
4.00E5
4.50E5
5.00E5
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass
Pb-210
Po-210
Ra-226
Ra-228
Th-227
Th-228
Th-230
Th-232
U-235
U-238
Pa-231

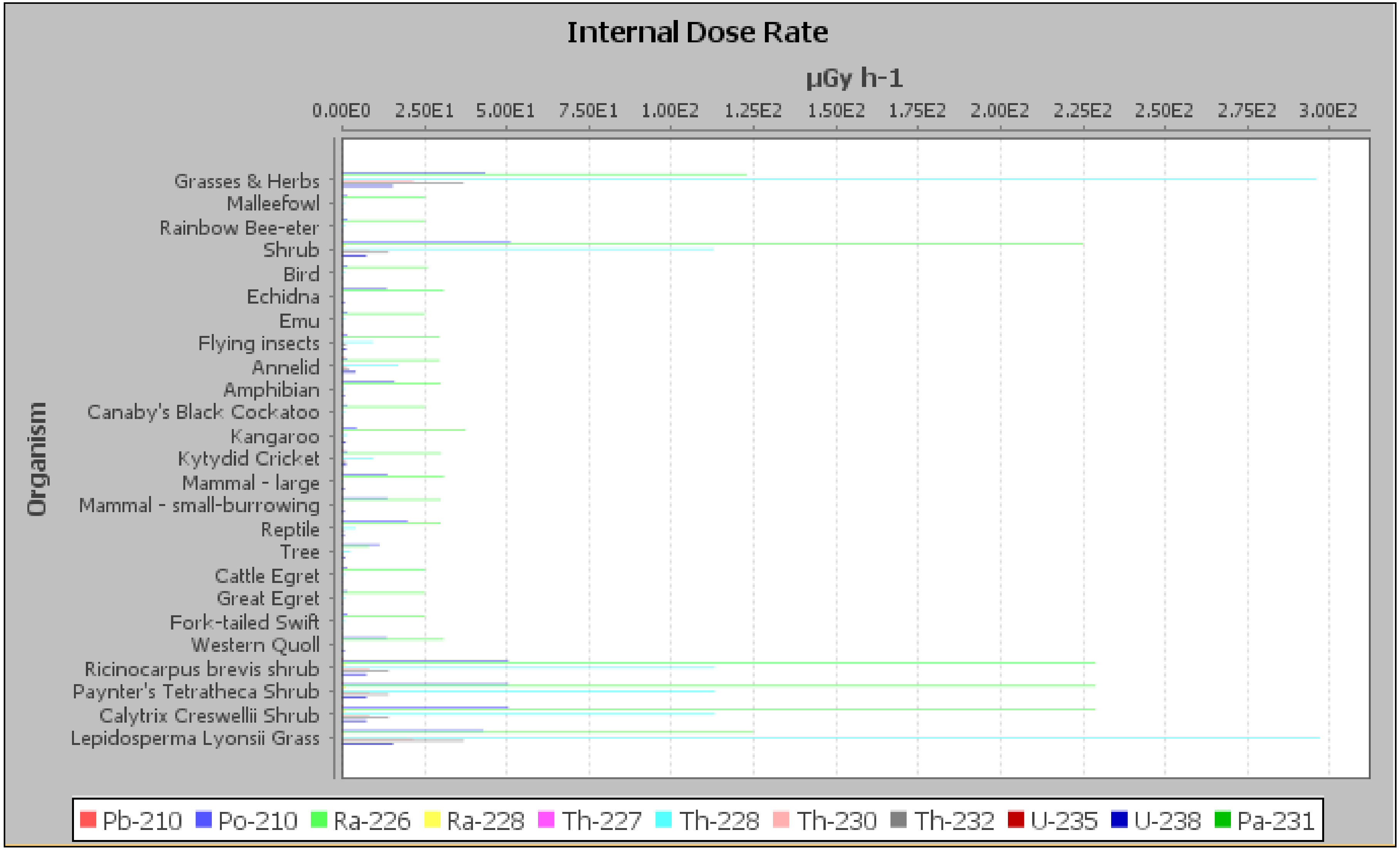

Total Dose Rate per organism
µGy h-1
0.00E0
5.00E3
1.00E4
1.50E4
2.00E4
2.50E4
3.00E4
3.50E4
4.00E4
4.50E4
5.00E4
5.50E4
6.00E4
6.50E4
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass

Appendix E

ERICA Assessment Category A Waste


Activity Concentration in soil or air
Bq kg-1 d.w. or Bq m-3
1.00E4
9.00E3
8.00E3
7.00E3
6.00E3
5.00E3
4.00E3
3.00E3
2.00E3
1.00E3
0.00E0
Isotope
Pb-210
Po-210
Ra-226
Ra-228
Th-227
Th-228
Th-230
Th-232
U-235
U-238
Pa-231


External Dose Rate
µGy h-1
0.00E0
1.00E0
2.00E0
3.00E0
4.00E0
5.00E0
6.00E0
7.00E0
8.00E0
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass
Pb-210
Po-210
Ra-226
Ra-228
Th-227
Th-228
Th-230
Th-232
U-235
U-238
Pa-231



Internal Dose Rate
µGy h-1
0.00E0
2.50E1
5.00E1
7.50E1
1.00E2
1.25E2
1.50E2
1.75E2
2.00E2
2.25E2
2.50E2
2.75E2
3.00E2
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass
Pb-210
Po-210
Ra-226
Ra-228
Th-227
Th-228
Th-230
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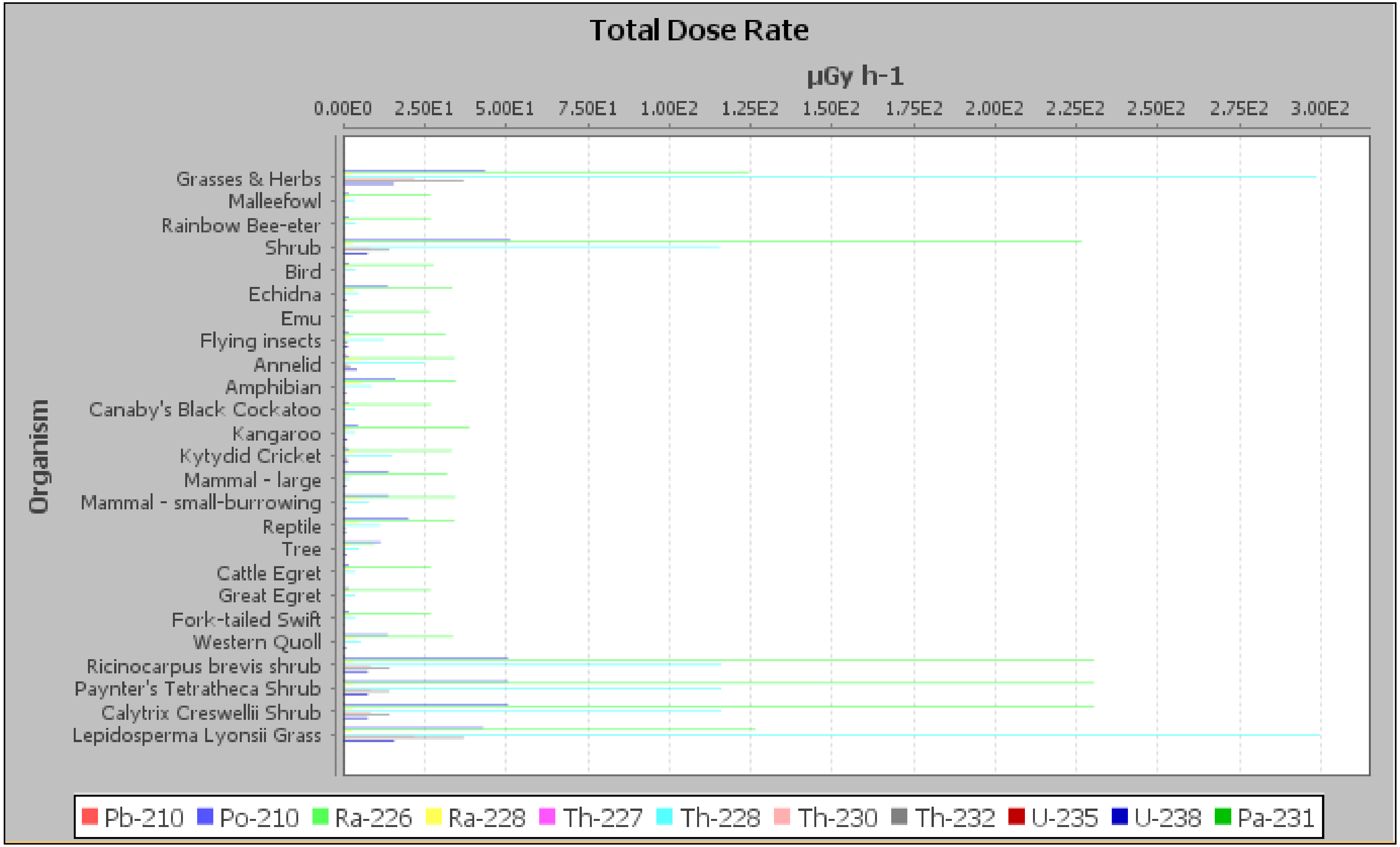
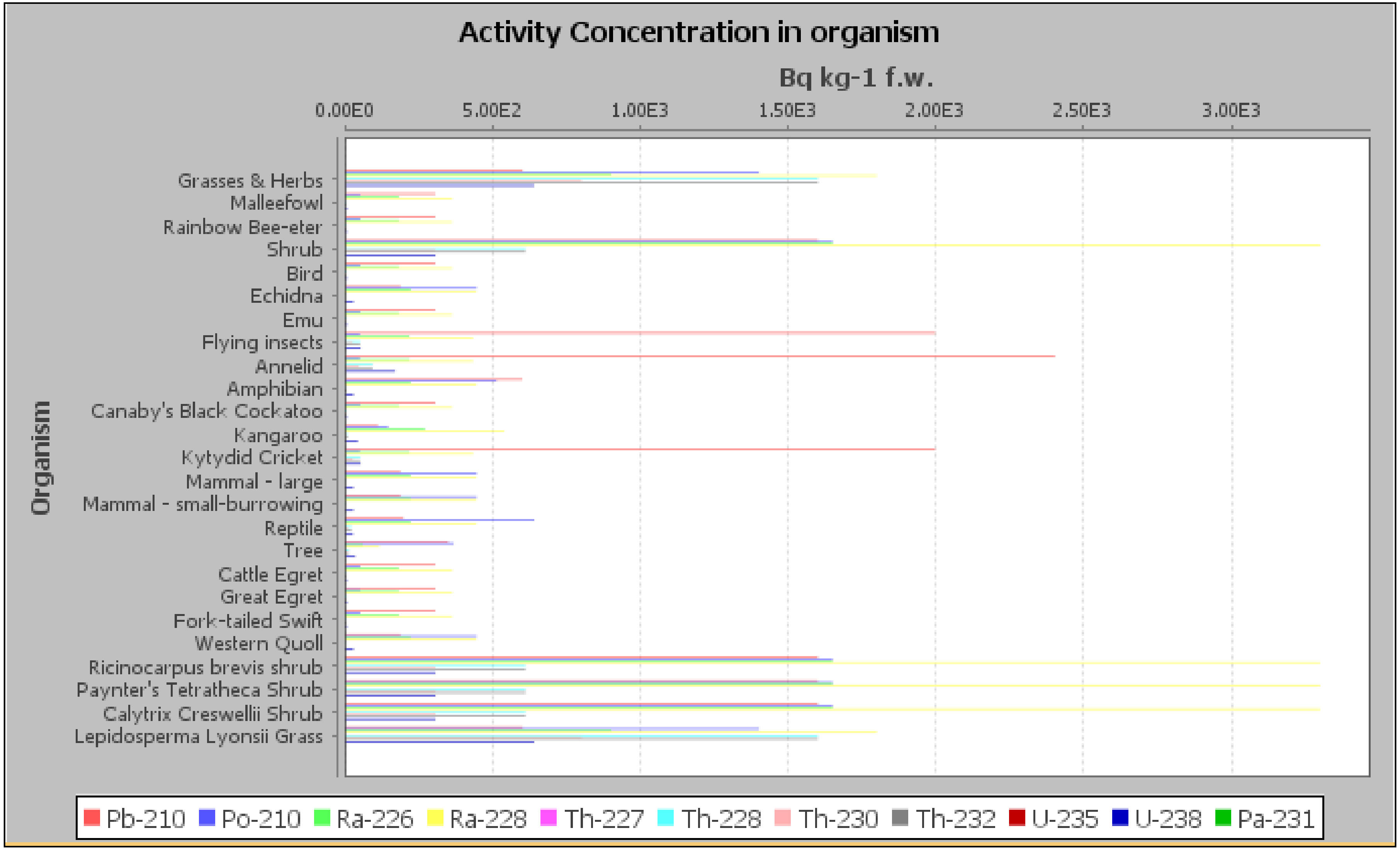
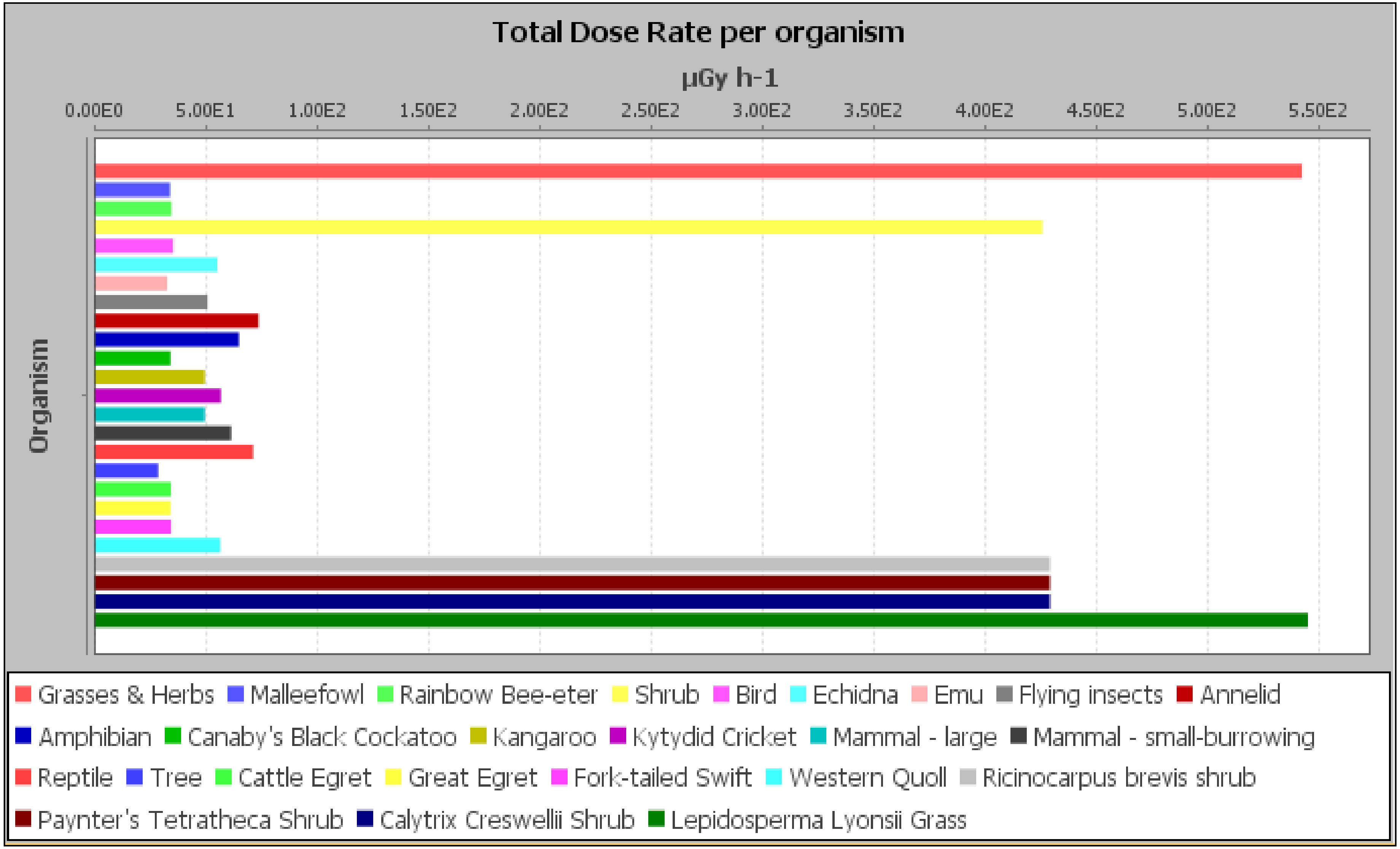
U-235
U-238
Pa-231



Total Dose Rate
µGy h-1
0.00E0
2.50E1
5.00E1
7.50E1
1.00E2
1.25E2
1.50E2
1.75E2
2.00E2
2.25E2
2.50E2
2.75E2
3.00E2
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass
Pb-210
Po-210
Ra-226
Ra-228
Th-227
Th-228
Th-230
Th-232
U-235
U-238
Pa-231

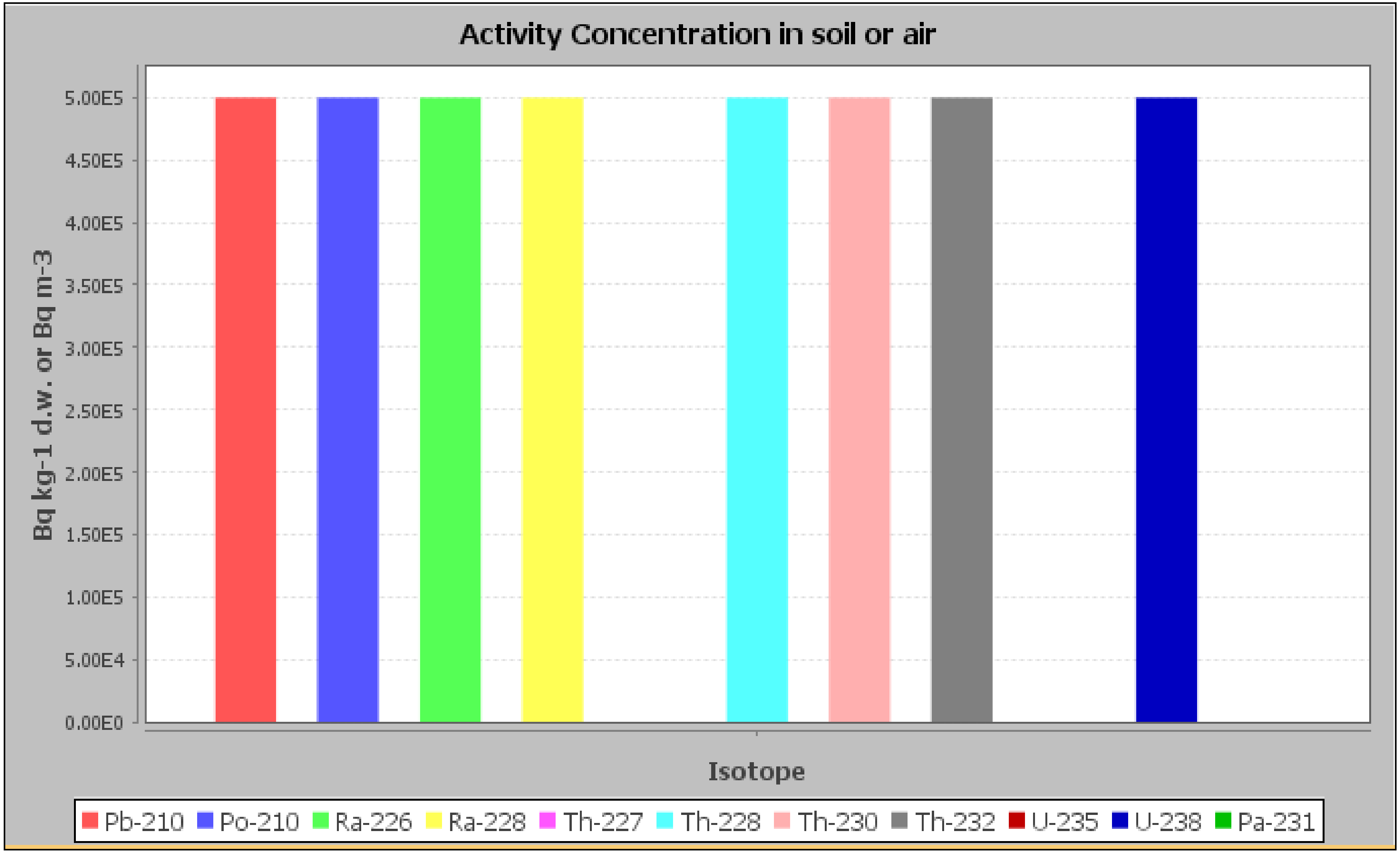


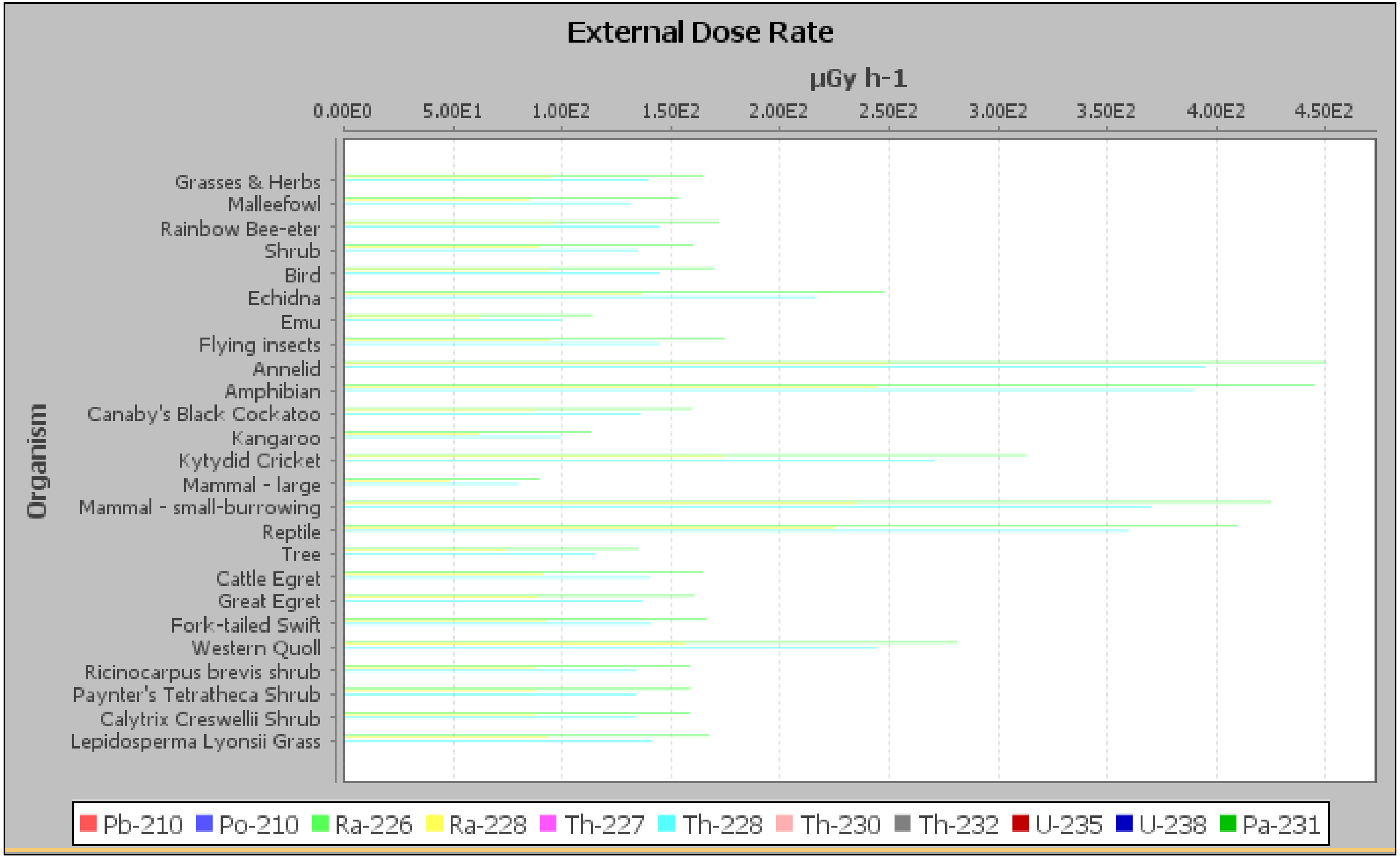
Activity Concentration in organism
Bq kg-1 f.w.
0.00E0
5.00E2
1.00E3
1.50E3
2.00E3
2.50E3
3.00E3
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass
Pb-210
Po-210
Ra-226
Ra-228
Th-227
Th-228
Th-230
Th-232
U-235
U-238
Pa-231


Total Dose Rate per organism
µGy h-1
0.00E0
5.00E1
1.00E2
1.50E2
2.00E2
2.50E2
3.00E2
3.50E2
4.00E2
4.50E2
5.00E2
5.50E2
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass

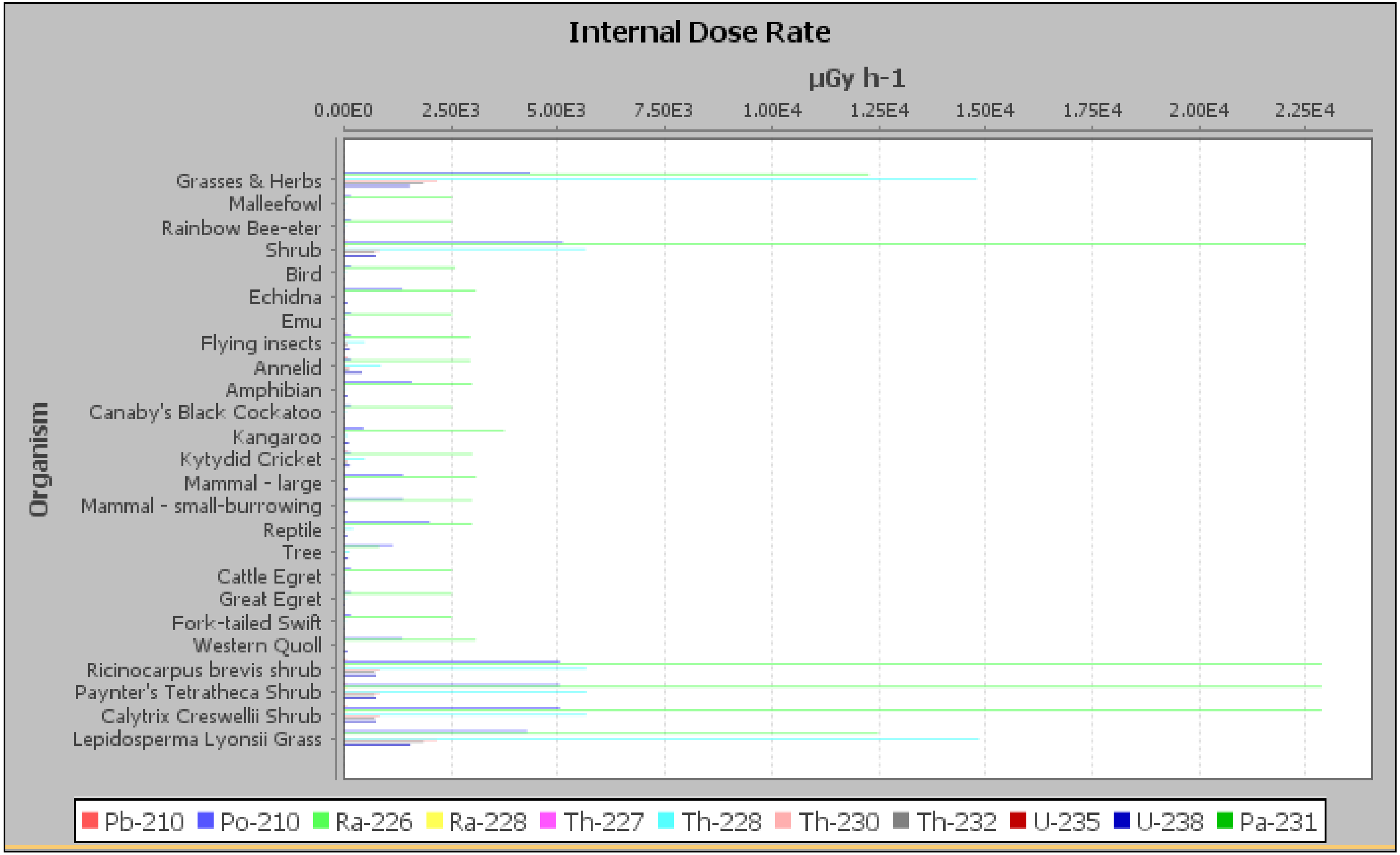
Appendix F

ERICA Assessment Category C Waste

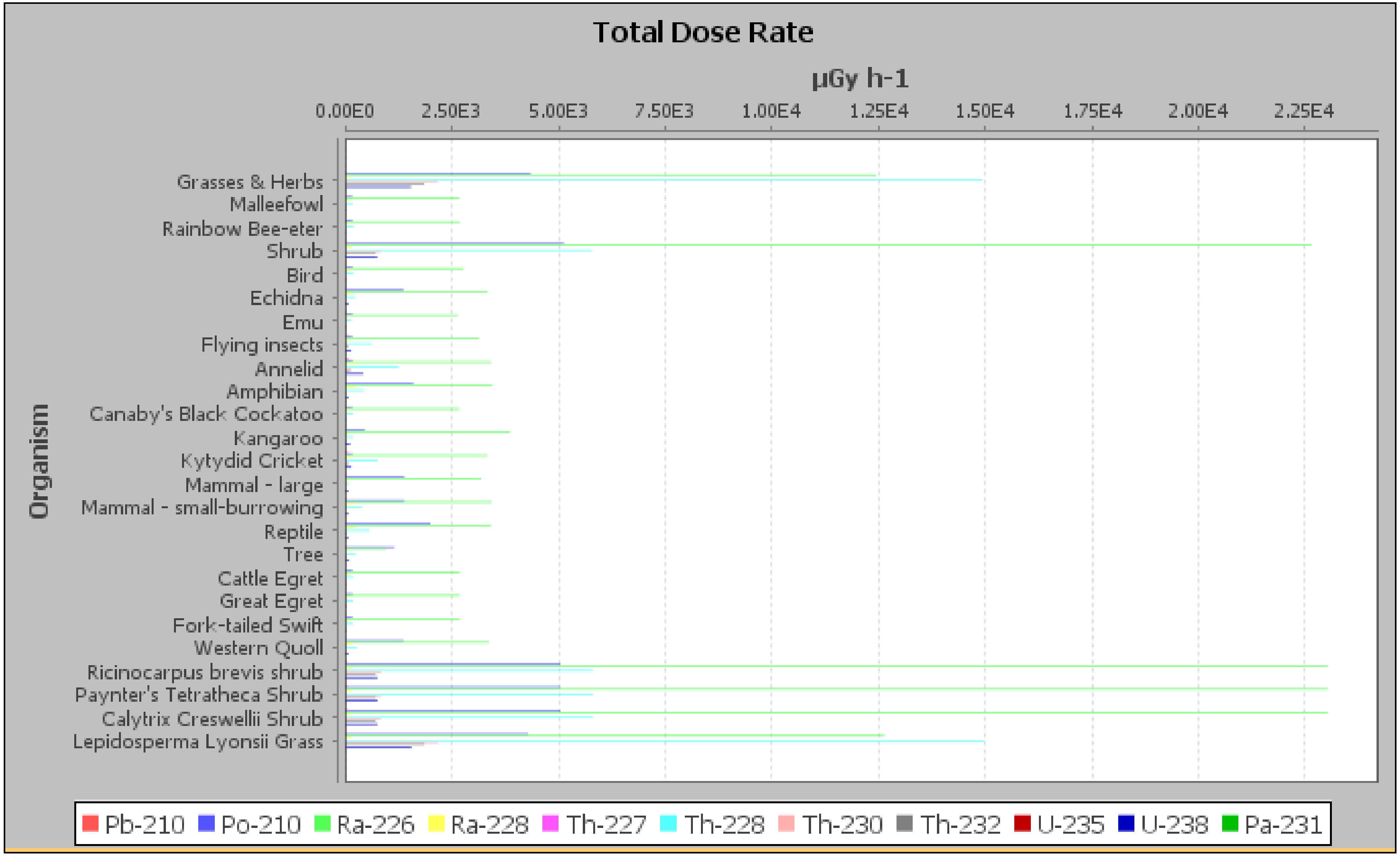

Activity Concentration in soil or air
Bq kg-1 d.w. or Bq m-3
5.00E5
4.50E5
4.00E5
3.50E5
3.00E5
2.50E5
2.00E5
1.50E5
1.00E5
5.00E4
0.00E0
Isotope
Pb-210
Po-210
Ra-226
Ra-228
Th-227
Th-228
Th-230
Th-232
U-235
U-238
Pa-231



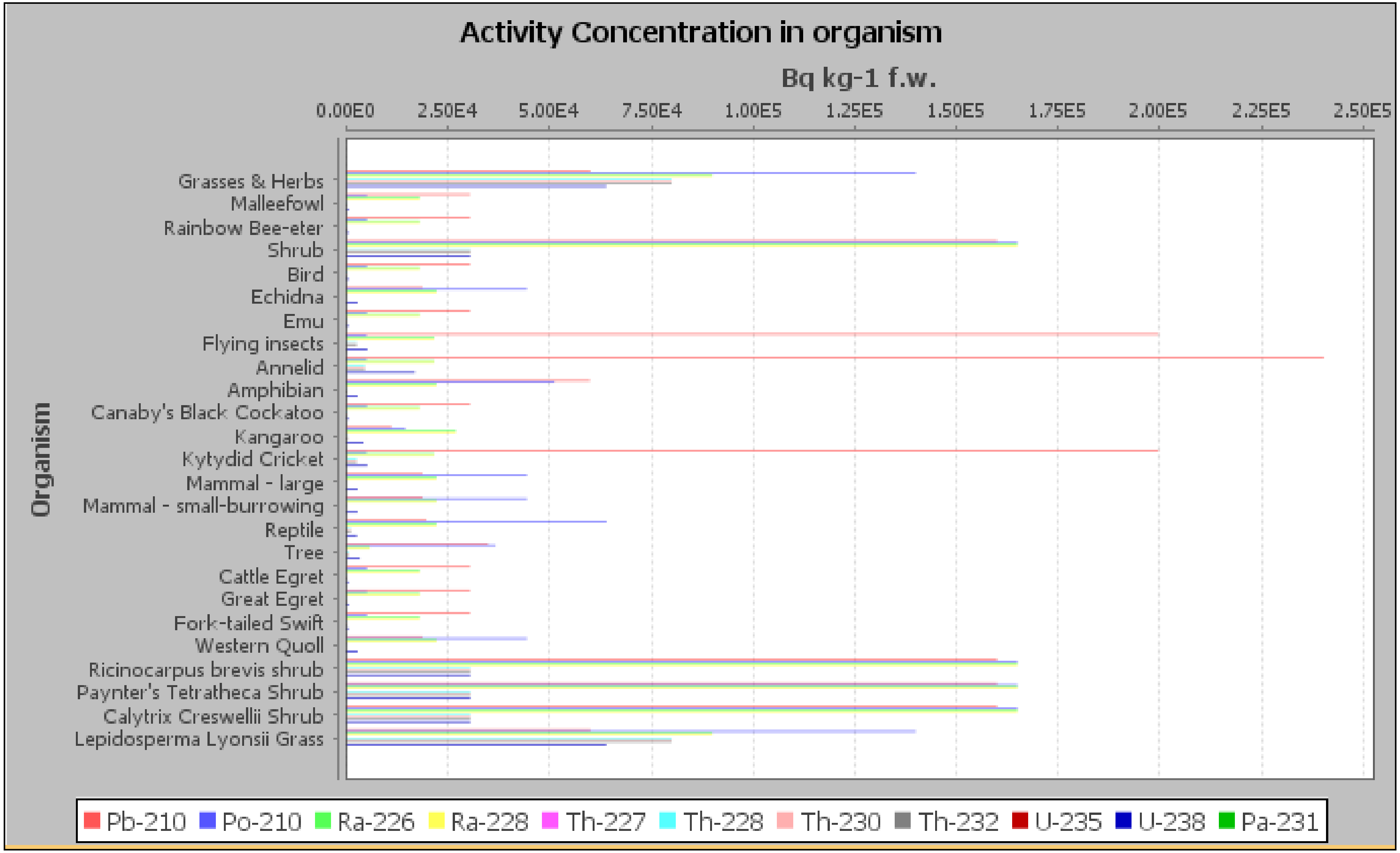
External Dose Rate
μGy h-1
0.00E0
5.00E1
1.00E2
1.50E2
2.00E2
2.50E2
3.00E2
3.50E2
4.00E2
4.50E2
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass
Pb-210
Po-210
Ra-226
Ra-228
Th-227
Th-228
Th-230
Th-232
U-235
U-238
Pa-231



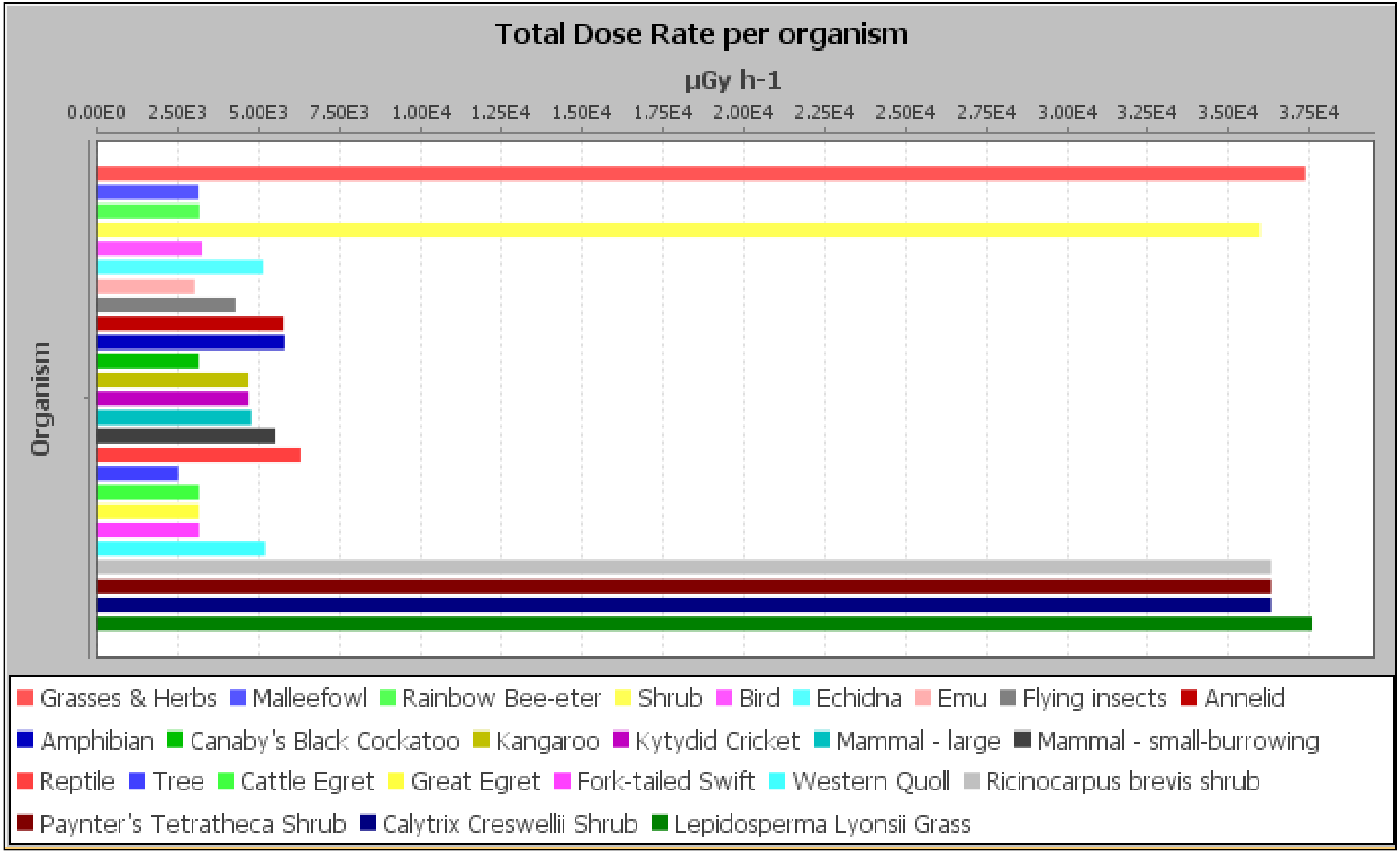
Internal Dose Rate
µGy h-1
0.00E0
2.50E3
5.00E3
7.50E3
1.00E4
1.25E4
1.50E4
1.75E4
2.00E4
2.25E4
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass
Pb-210
Po-210
Ra-226
Ra-228
Th-227
Th-228
Th-230
Th-232
U-235
U-238
Pa-231



Total Dose Rate
µGy h-1
0.00E0
2.50E3
5.00E3
7.50E3
1.00E4
1.25E4
1.50E4
1.75E4
2.00E4
2.25E4
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass
Pb-210
Po-210
Ra-226
Ra-228
Th-227
Th-228
Th-230
Th-232
U-235
U-238
Pa-231

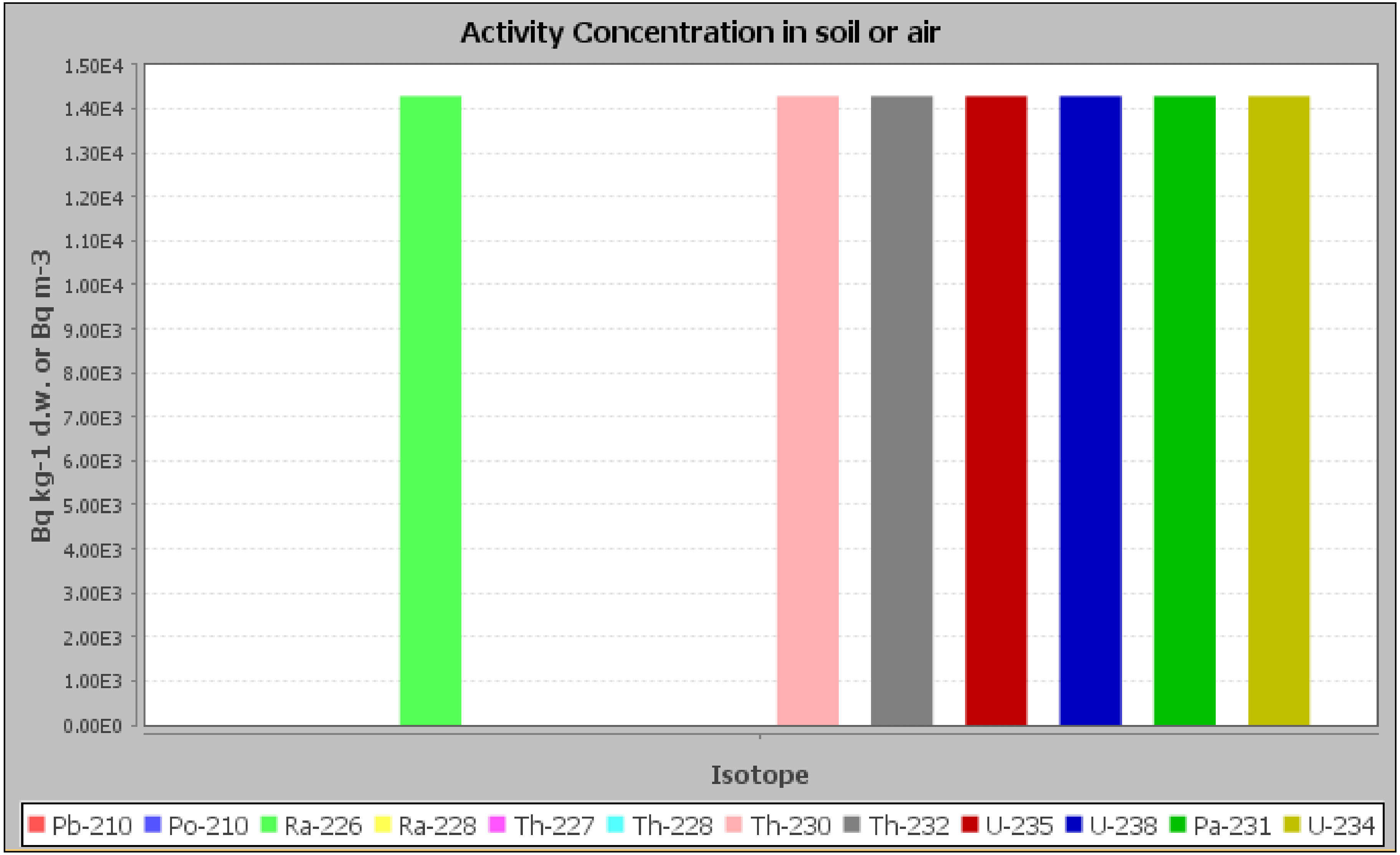


Activity Concentration in organism
Bq kg-1 f.w.
0.00E0
2.50E4
5.00E4
7.50E4
1.00E5
1.25E5
1.50E5
1.75E5
2.00E5
2.25E5
2.50E5
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass
Pb-210
Po-210
Ra-226
Ra-228
Th-227
Th-228
Th-230
Th-232
U-235
U-238
Pa-231

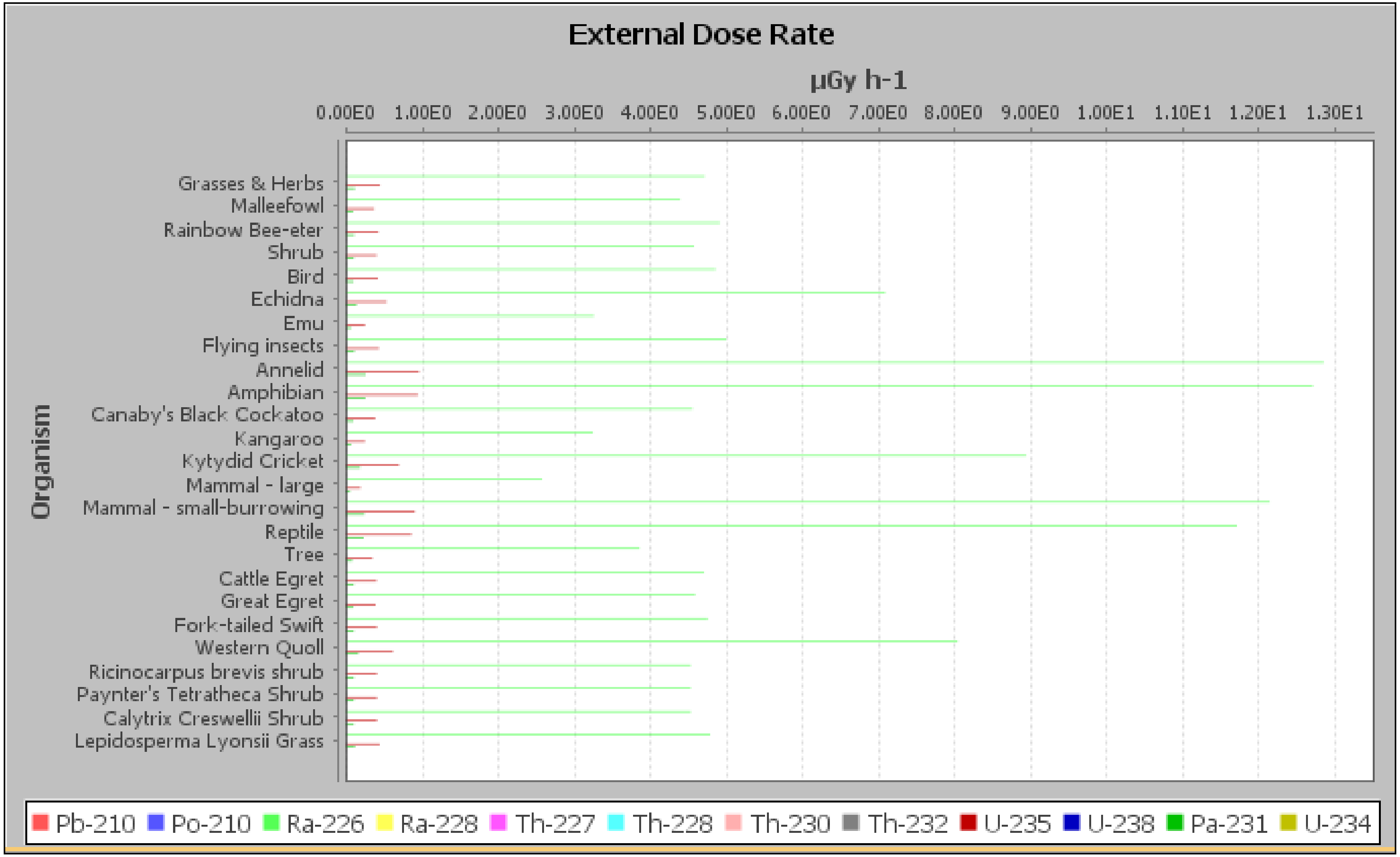

Total Dose Rate per organism
µGy h-1
0.00E0
2.50E3
5.00E3
7.50E3
1.00E4
1.25E4
1.50E4
1.75E4
2.00E4
2.25E4
2.50E4
2.75E4
3.00E4
3.25E4
3.50E4
3.75E4
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass

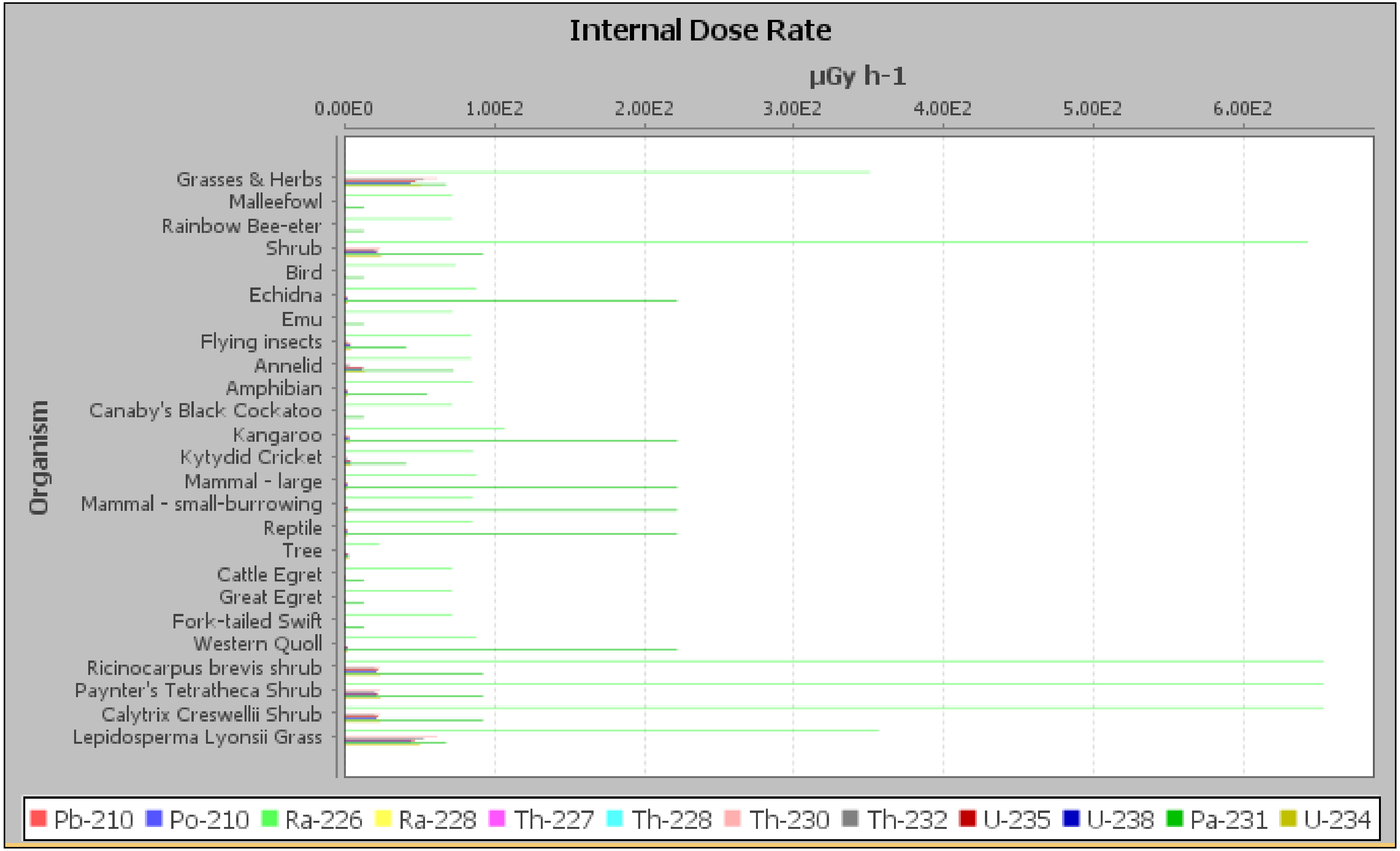
Appendix G

ERICA Assessment VLLW

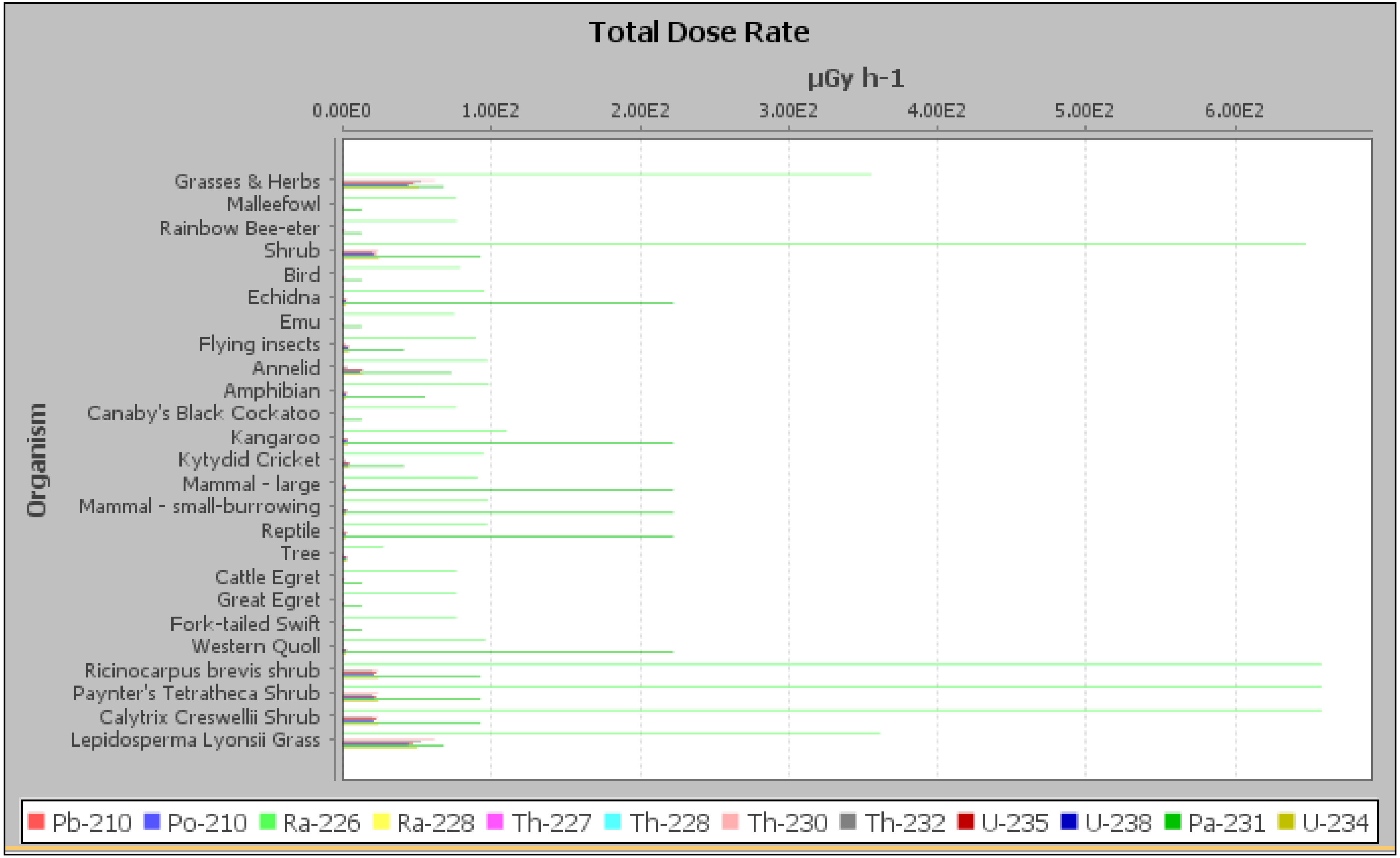


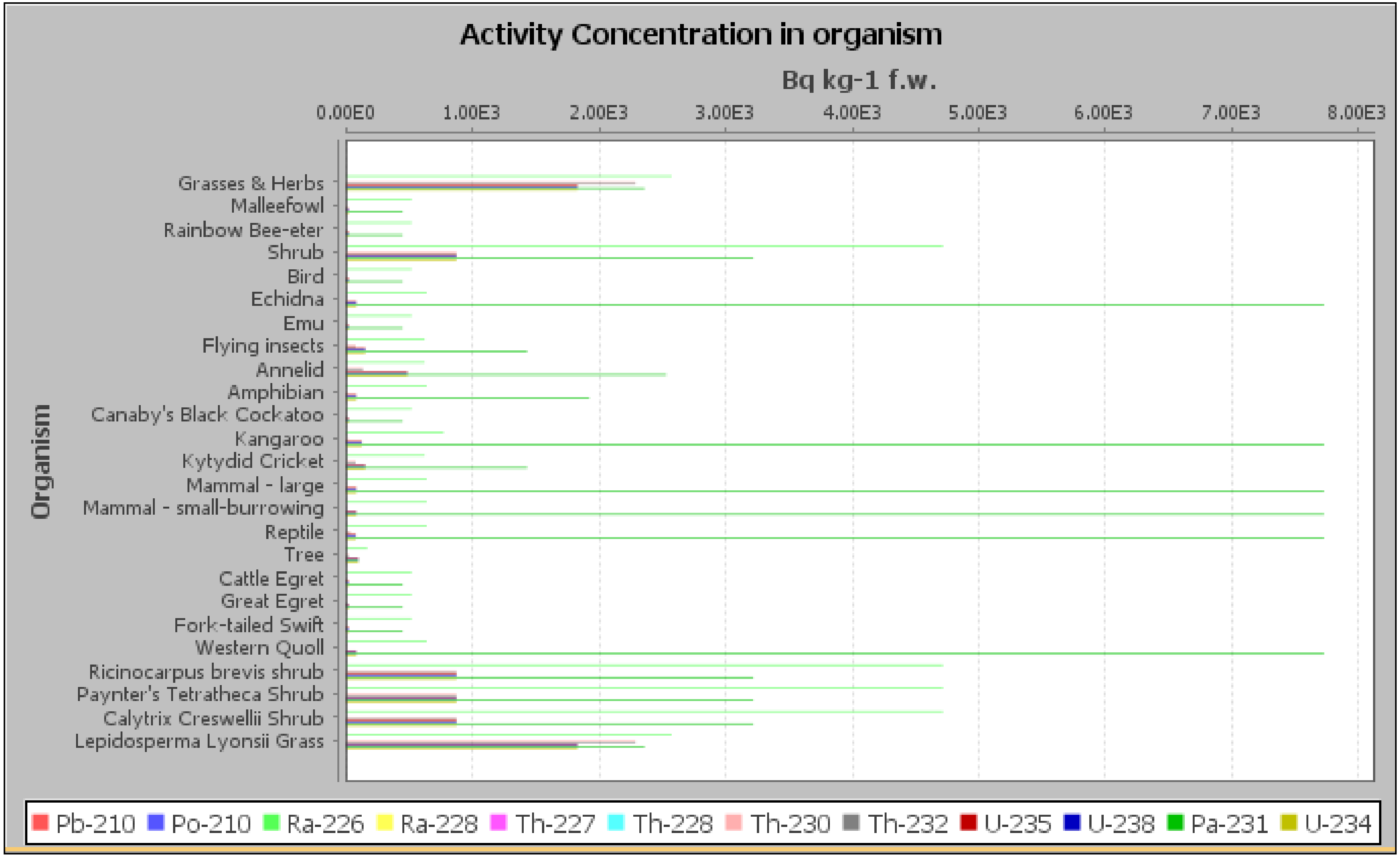
Activity Concentration in soil or air
Bq kg-1 d.w. or Bq m-3
1.50E4
1.40E4
1.30E4
1.20E4
1.10E4
1.00E4
9.00E3
8.00E3
7.00E3
6.00E3
5.00E3
4.00E3
3.00E3
2.00E3
1.00E3
0.00E0
Isotope
Pb-210
Po-210
Ra-226
Ra-228
Th-227
Th-228
Th-230
Th-232
U-235
U-238
Pa-231
U-234


External Dose Rate
µGy h-1
0.00E0
1.00E0
2.00E0
3.00E0
4.00E0
5.00E0
6.00E0
7.00E0
8.00E0
9.00E0
1.00E1
1.10E1
1.20E1
1.30E1
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass
Pb-210
Po-210
Ra-226
Ra-228
Th-227
Th-228
Th-230
Th-232
U-235
U-238
Pa-231
U-234

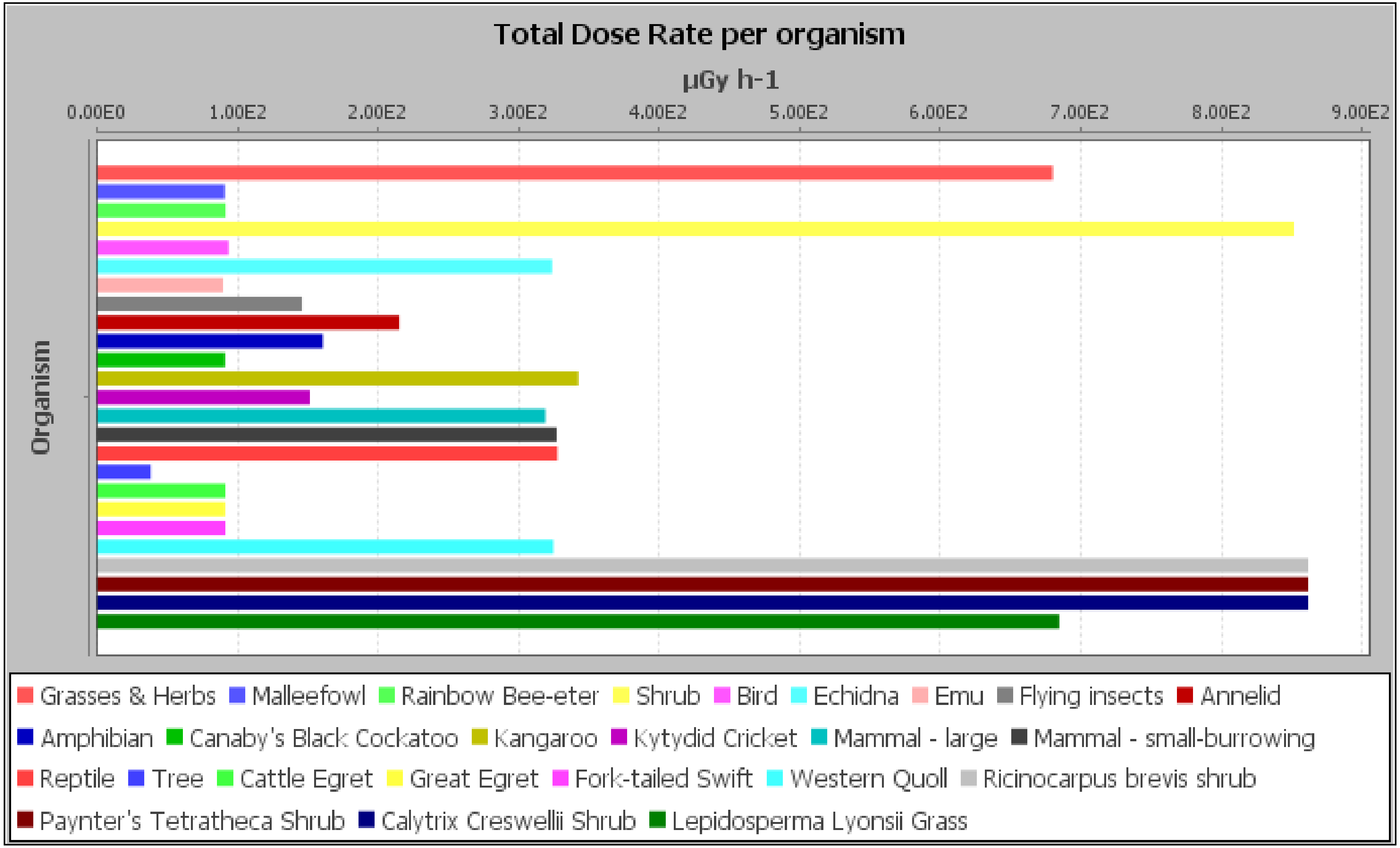


Internal Dose Rate
µGy h-1
0.00E0
1.00E2
2.00E2
3.00E2
4.00E2
5.00E2
6.00E2
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass
Pb-210
Po-210
Ra-226
Ra-228
Th-227
Th-228
Th-230
Th-232
U-235
U-238
Pa-231
U-234


Total Dose Rate
µGy h-1
0.00E0
1.00E2
2.00E2
3.00E2
4.00E2
5.00E2
6.00E2
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass
Pb-210
Po-210
Ra-226
Ra-228
Th-227
Th-228
Th-230
Th-232
U-235
U-238
Pa-231
U-234



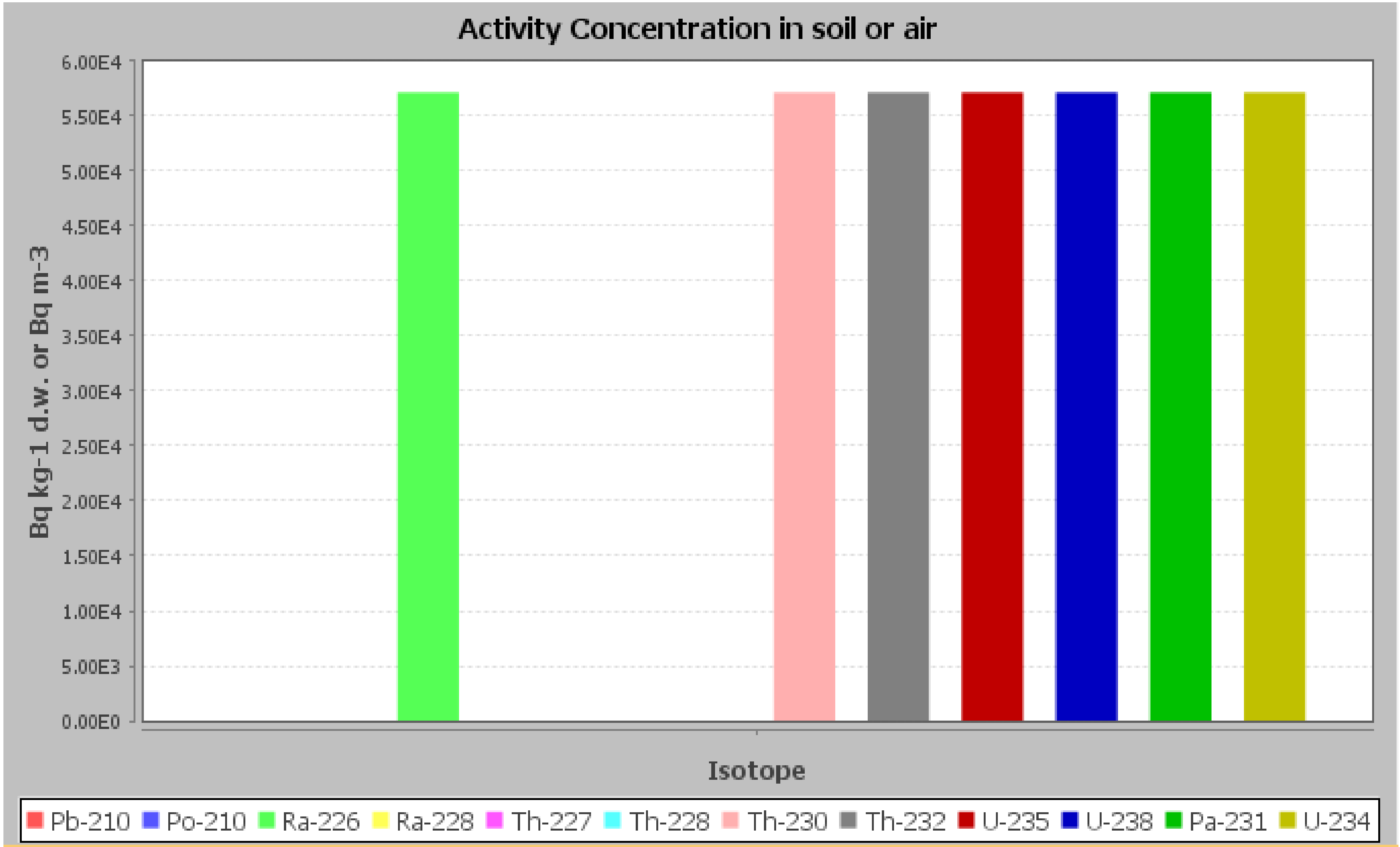
Activity Concentration in organism
Bq kg-1 f.w.
0.00E0
1.00E3
2.00E3
3.00E3
4.00E3
5.00E3
6.00E3
7.00E3
8.00E3
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass
Pb-210
Po-210
Ra-226
Ra-228
Th-227
Th-228
Th-230
Th-232
U-235
U-238
Pa-231
U-234

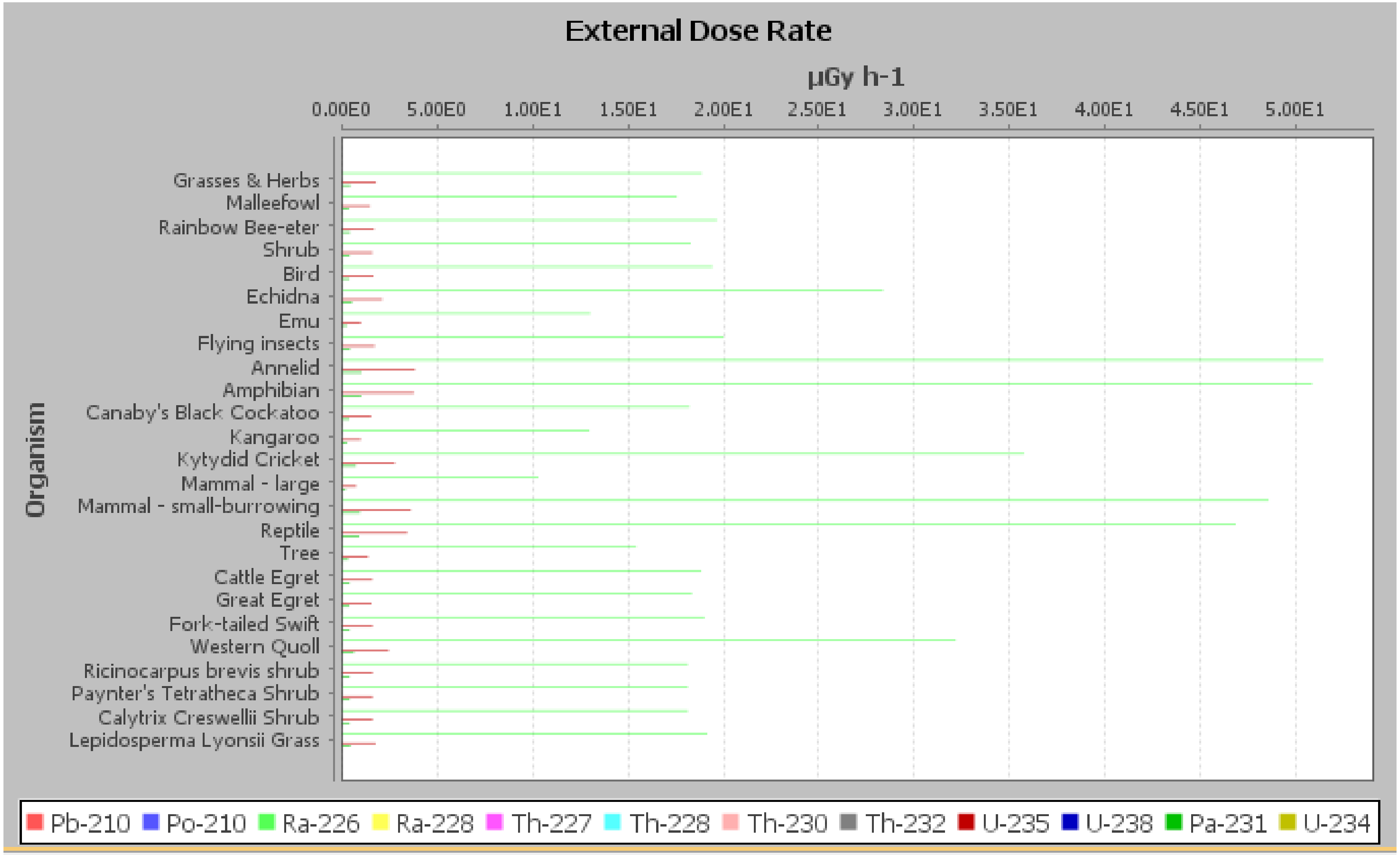


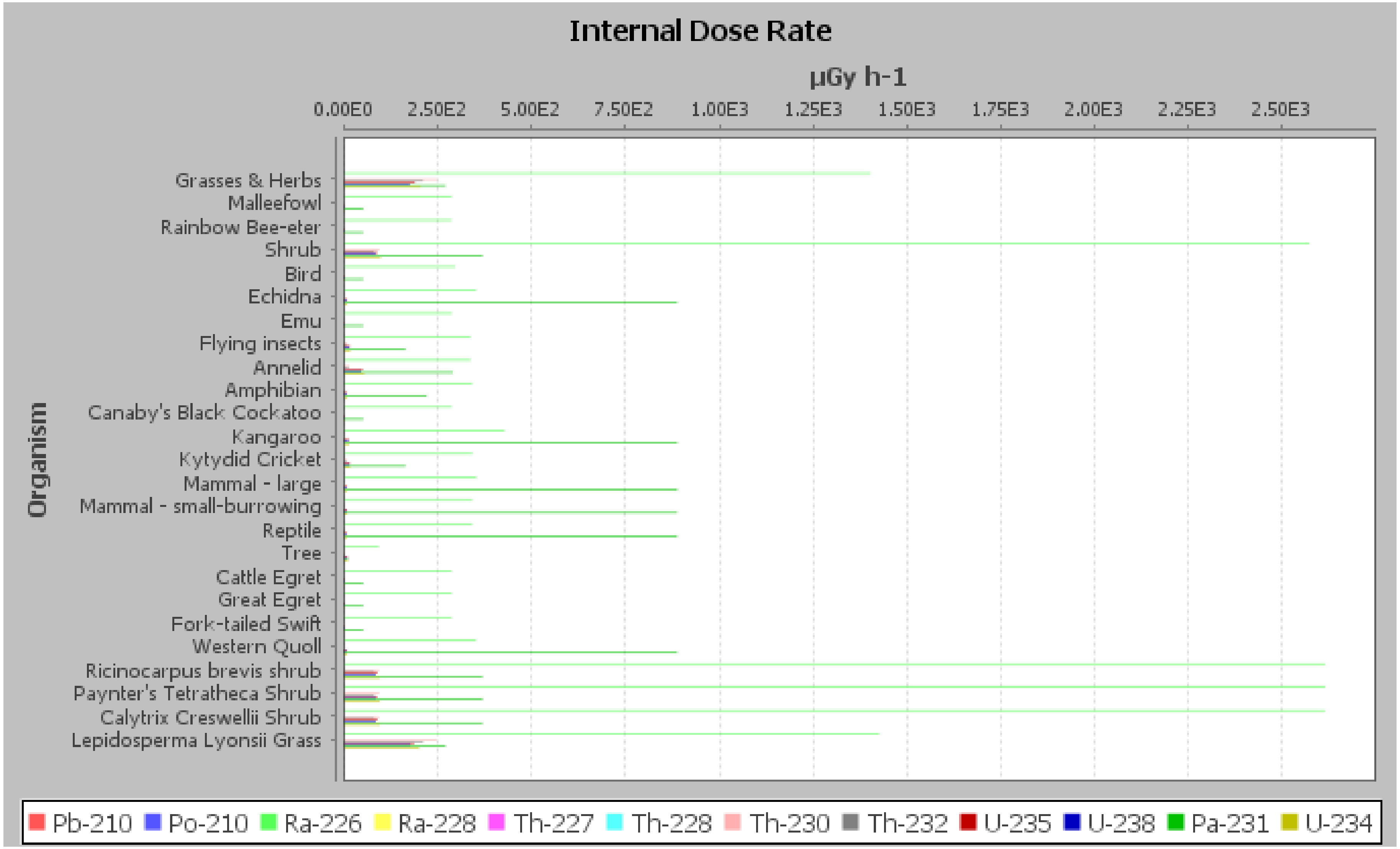
Total Dose Rate per organism
µGy h-1
0.00E0
1.00E2
2.00E2
3.00E2
4.00E2
5.00E2
6.00E2
7.00E2
8.00E2
9.00E2
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass

Appendix H

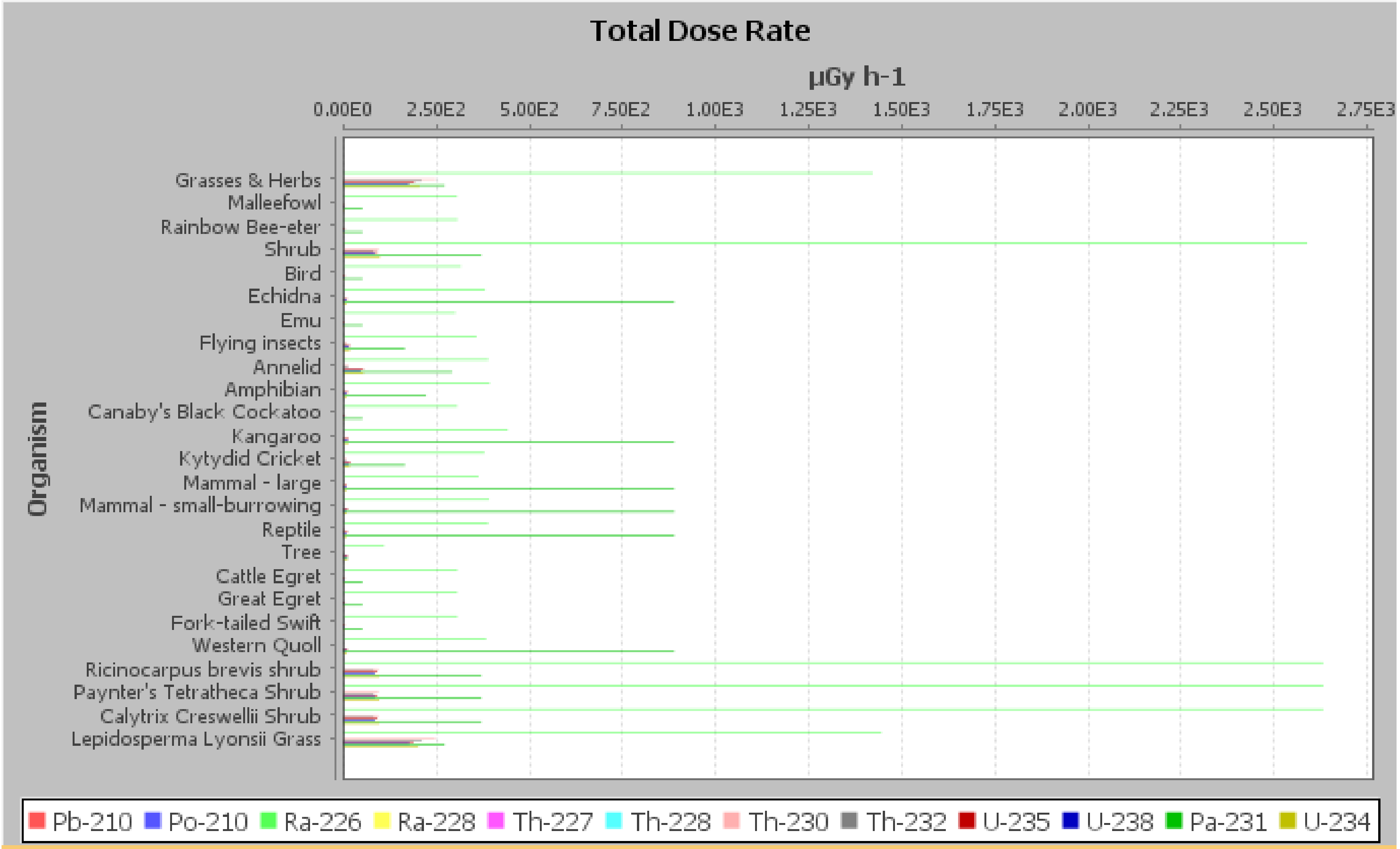
ERICA Assessment LLW

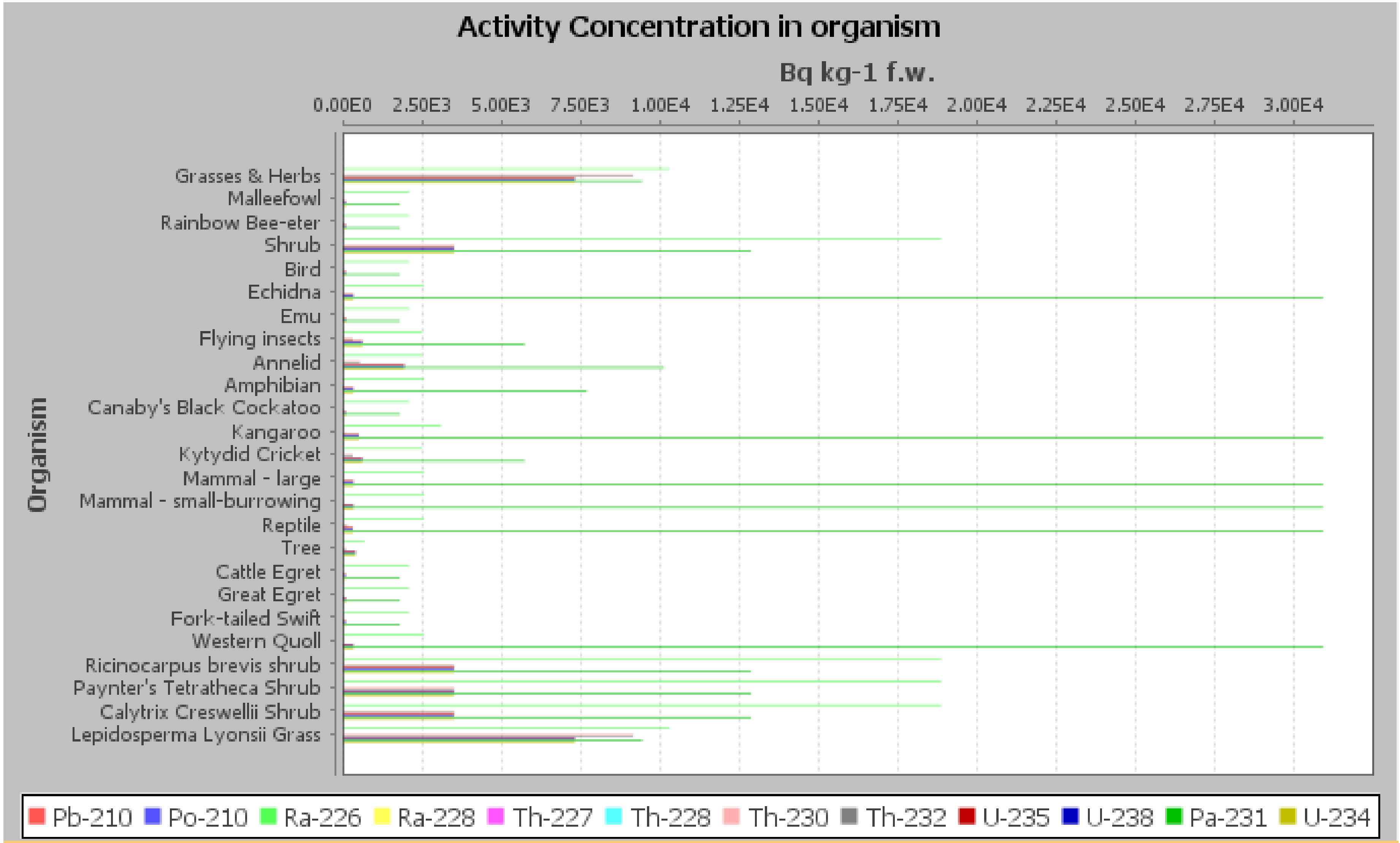

Activity Concentration in soil or air
Bq kg-1 d.w. or Bq m-3
6.00E4
5.50E4
5.00E4
4.50E4
4.00E4
3.50E4
3.00E4
2.50E4
2.00E4
1.50E4
1.00E4
5.00E3
0.00E0
Isotope
Pb-210 Po-210 Ra-226 Ra-228 Th-227 Th-228 Th-230 Th-232 U-235 U-238 Pa-231 U-234

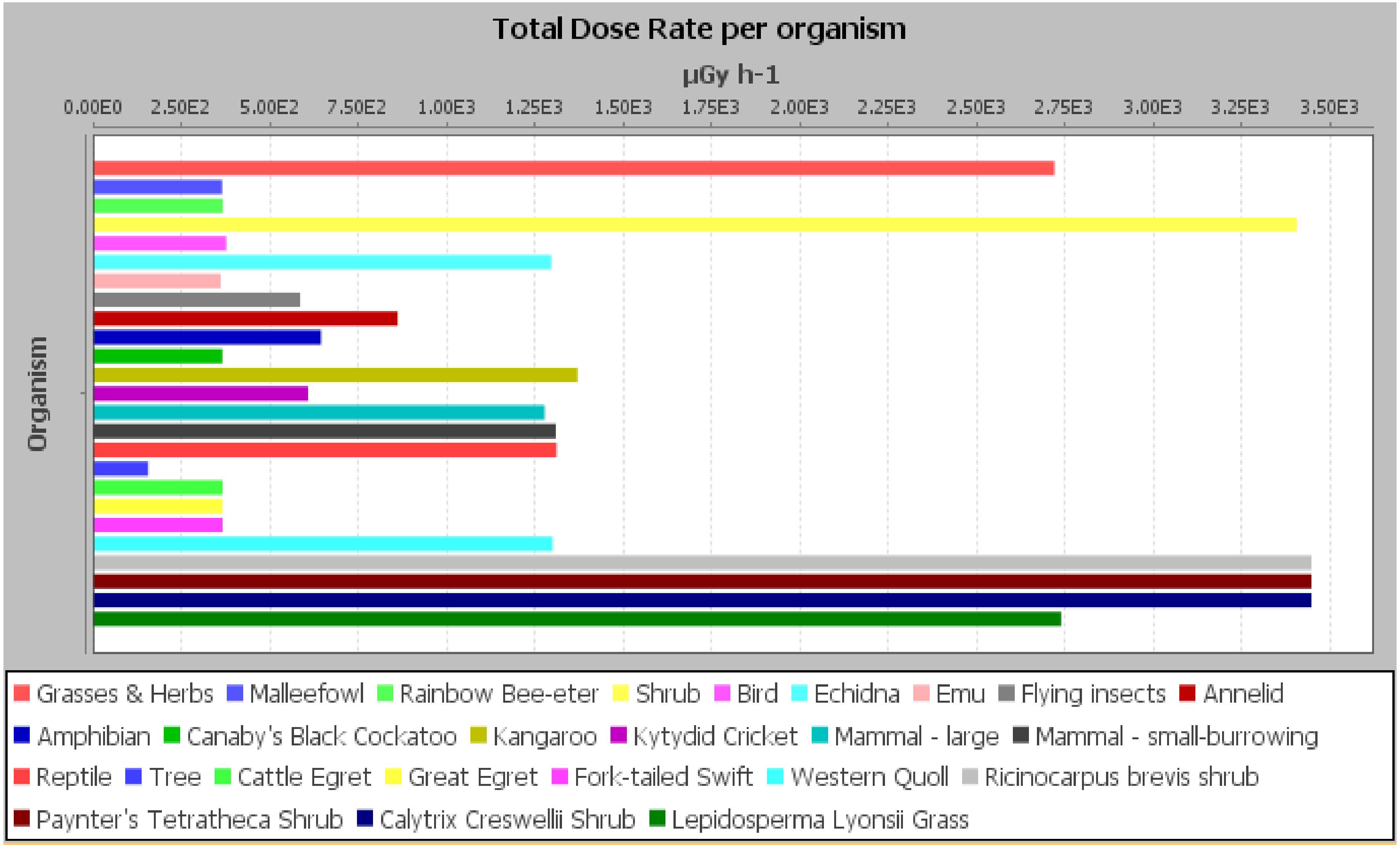

External Dose Rate
µGy h-1
0.00E0
5.00E0
1.00E1
1.50E1
2.00E1
2.50E1
3.00E1
3.50E1
4.00E1
4.50E1
5.00E1
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass
Pb-210
Po-210
Ra-226
Ra-228
Th-227
Th-228
Th-230
Th-232
U-235
U-238
Pa-231
U-234



Internal Dose Rate
µGy h-1
0.00E0
2.50E2
5.00E2
7.50E2
1.00E3
1.25E3
1.50E3
1.75E3
2.00E3
2.25E3
2.50E3
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass
Pb-210
Po-210
Ra-226
Ra-228
Th-227
Th-228
Th-230
Th-232
U-235
U-238
Pa-231
U-234

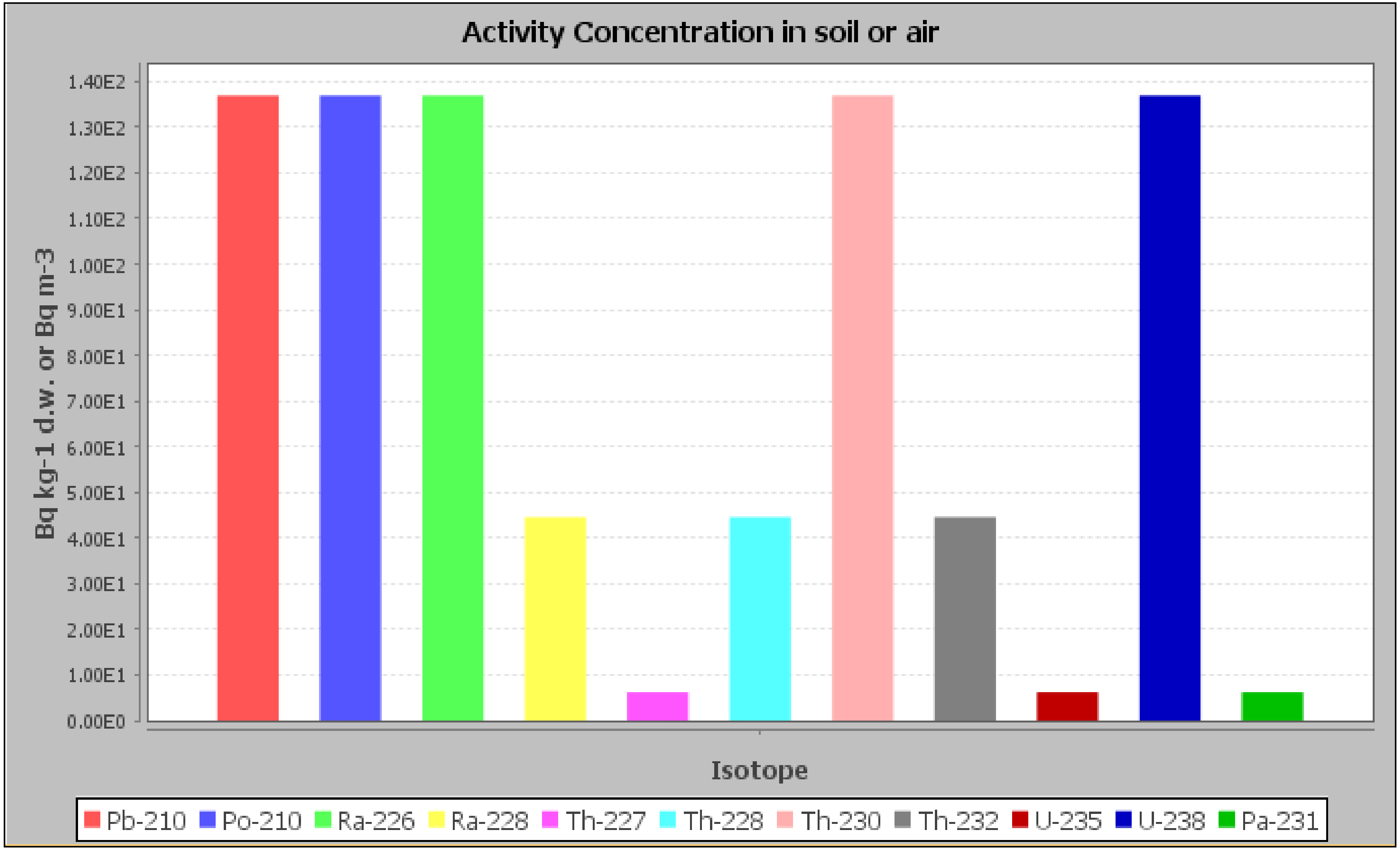

Total Dose Rate
µGy h-1
0.00E0
2.50E2
5.00E2
7.50E2
1.00E3
1.25E3
1.50E3
1.75E3
2.00E3
2.25E3
2.50E3
2.75E3
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass
Pb-210
Po-210
Ra-226
Ra-228
Th-227
Th-228
Th-230
Th-232
U-235
U-238
Pa-231
U-234

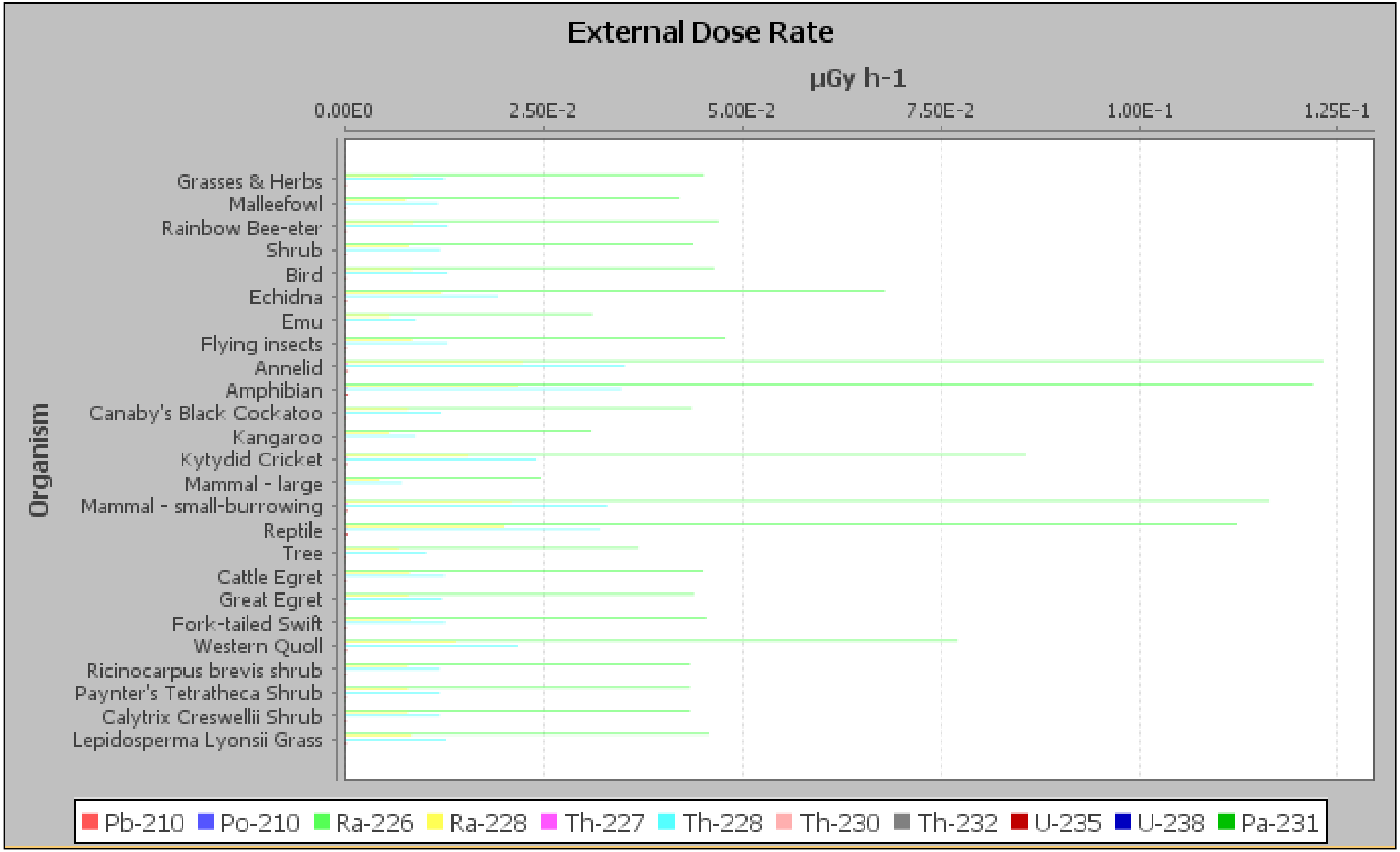

Activity Concentration in organism
Bq kg-1 f.w.
0.00E0
2.50E3
5.00E3
7.50E3
1.00E4
1.25E4
1.50E4
1.75E4
2.00E4
2.25E4
2.50E4
2.75E4
3.00E4
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass
Pb-210
Po-210
Ra-226
Ra-228
Th-227
Th-228
Th-230
Th-232
U-235
U-238
Pa-231
U-234


Total Dose Rate per organism
µGy h-1
0.00E0
2.50E2
5.00E2
7.50E2
1.00E3
1.25E3
1.50E3
1.75E3
2.00E3
2.25E3
2.50E3
2.75E3
3.00E3
3.25E3
3.50E3
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass

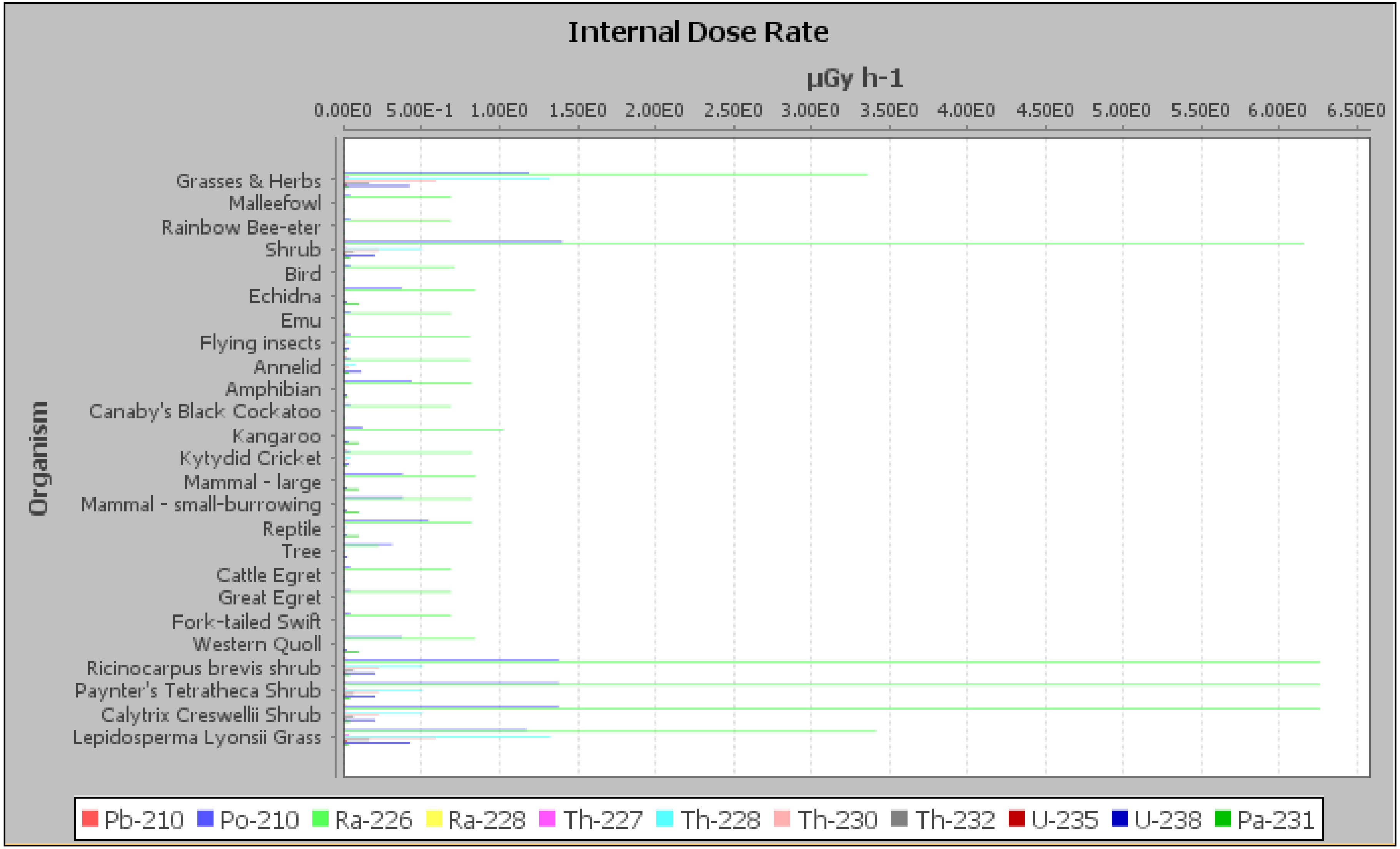
Appendix I

ERICA Assessment Post Closure


Activity Concentration in soil or air
1.40E2
1.30E2
1.20E2
1.10E2
1.00E2
9.00E1
8.00E1
7.00E1
6.00E1
5.00E1
4.00E1
3.00E1
2.00E1
1.00E1
0.00E0
Bq kg-1 d.w. or Bq m-3
Isotope
Pb-210 Po-210 Ra-226 Ra-228 Th-227 Th-228 Th-230 Th-232 U-235 U-238 Pa-231



External Dose Rate
µGy h-1
0.00E0
2.50E-2
5.00E-2
7.50E-2
1.00E-1
1.25E-1
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
Great Egret
Fork-tailed Swift
Western Quoll
Ricinocarpus brevis shrub
Paynter's Tetratheca Shrub
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass
Pb-210
Po-210
Ra-226
Ra-228
Th-227
Th-228
Th-230
Th-232
U-235
U-238
Pa-231



Internal Dose Rate
µGy h-1
0.00E0
5.00E-1
1.00E0
1.50E0
2.00E0
2.50E0
3.00E0
3.50E0
4.00E0
4.50E0
5.00E0
5.50E0
6.00E0
6.50E0
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
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Th-228
Th-230
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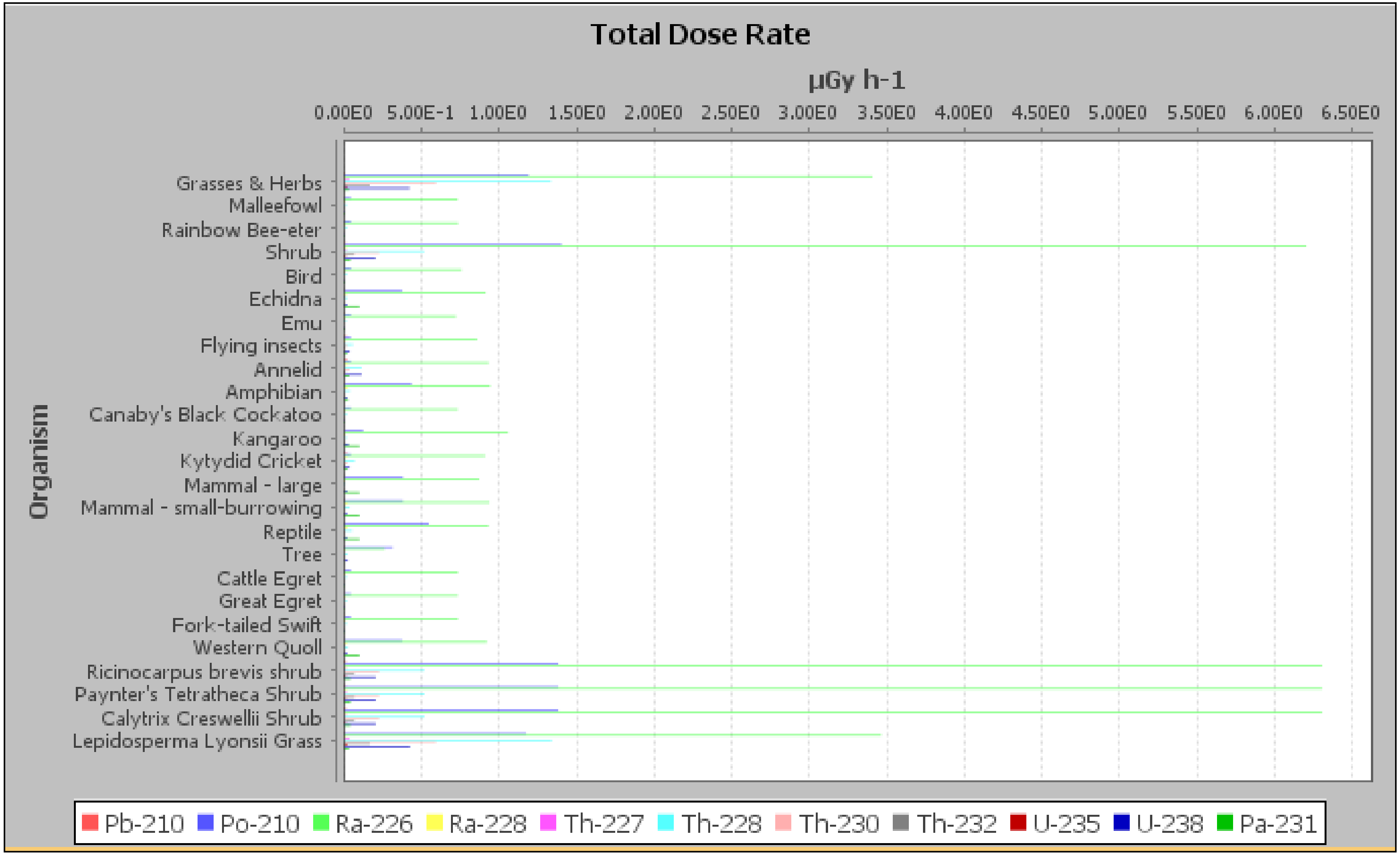
U-235
U-238
Pa-231



Total Dose Rate
µGy h-1
0.00E0 5.00E-1 1.00E0 1.50E0 2.00E0 2.50E0 3.00E0 3.50E0 4.00E0 4.50E0 5.00E0 5.50E0 6.00E0 6.50E0
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
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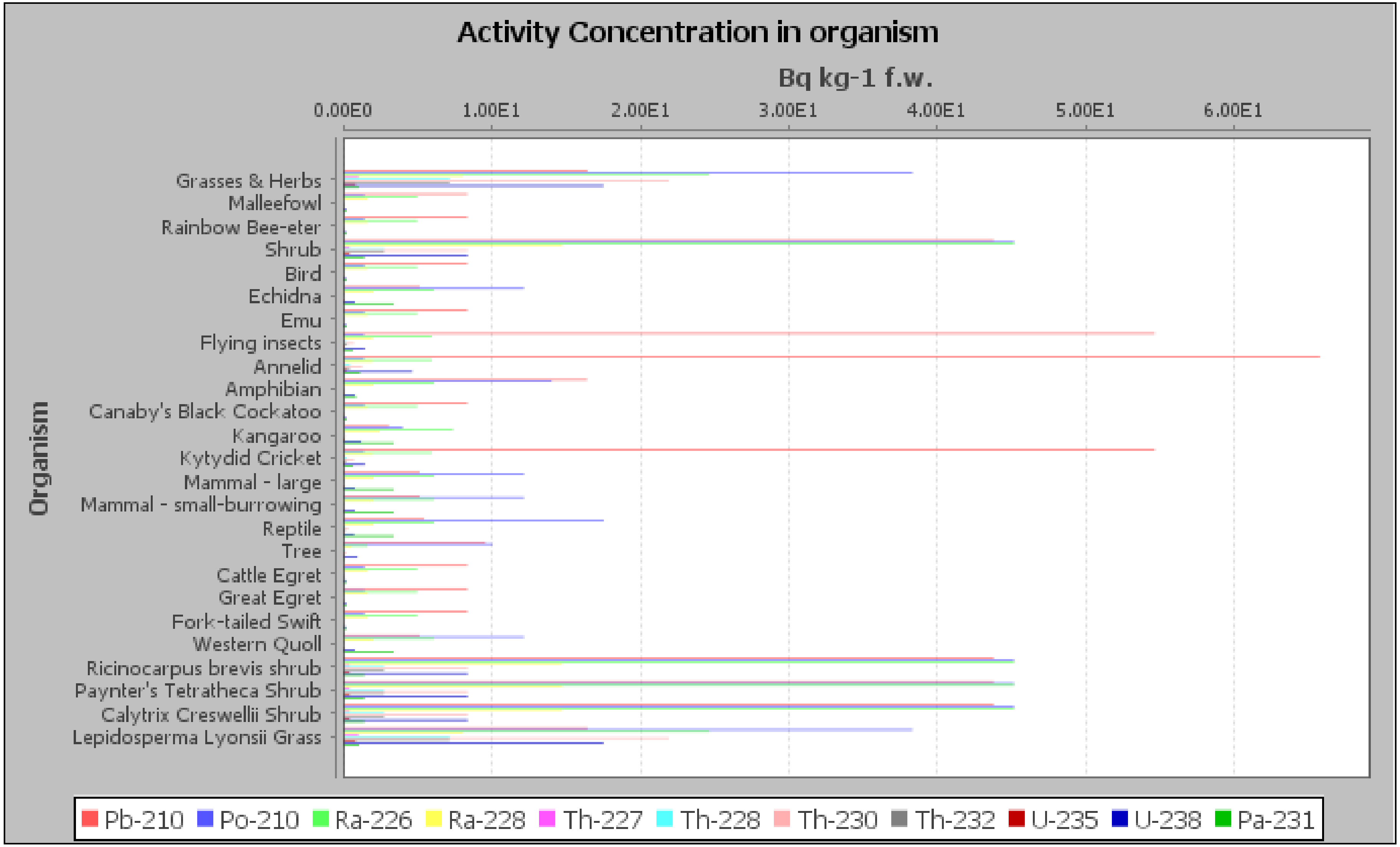

Activity Concentration in organism
Bq kg-1 f.w.
0.00E0
1.00E1
2.00E1
3.00E1
4.00E1
5.00E1
6.00E1
Organism
Grasses & Herbs
Malleefowl
Rainbow Bee-eter
Shrub
Bird
Echidna
Emu
Flying insects
Annelid
Amphibian
Canaby's Black Cockatoo
Kangaroo
Kytydid Cricket
Mammal - large
Mammal - small-burrowing
Reptile
Tree
Cattle Egret
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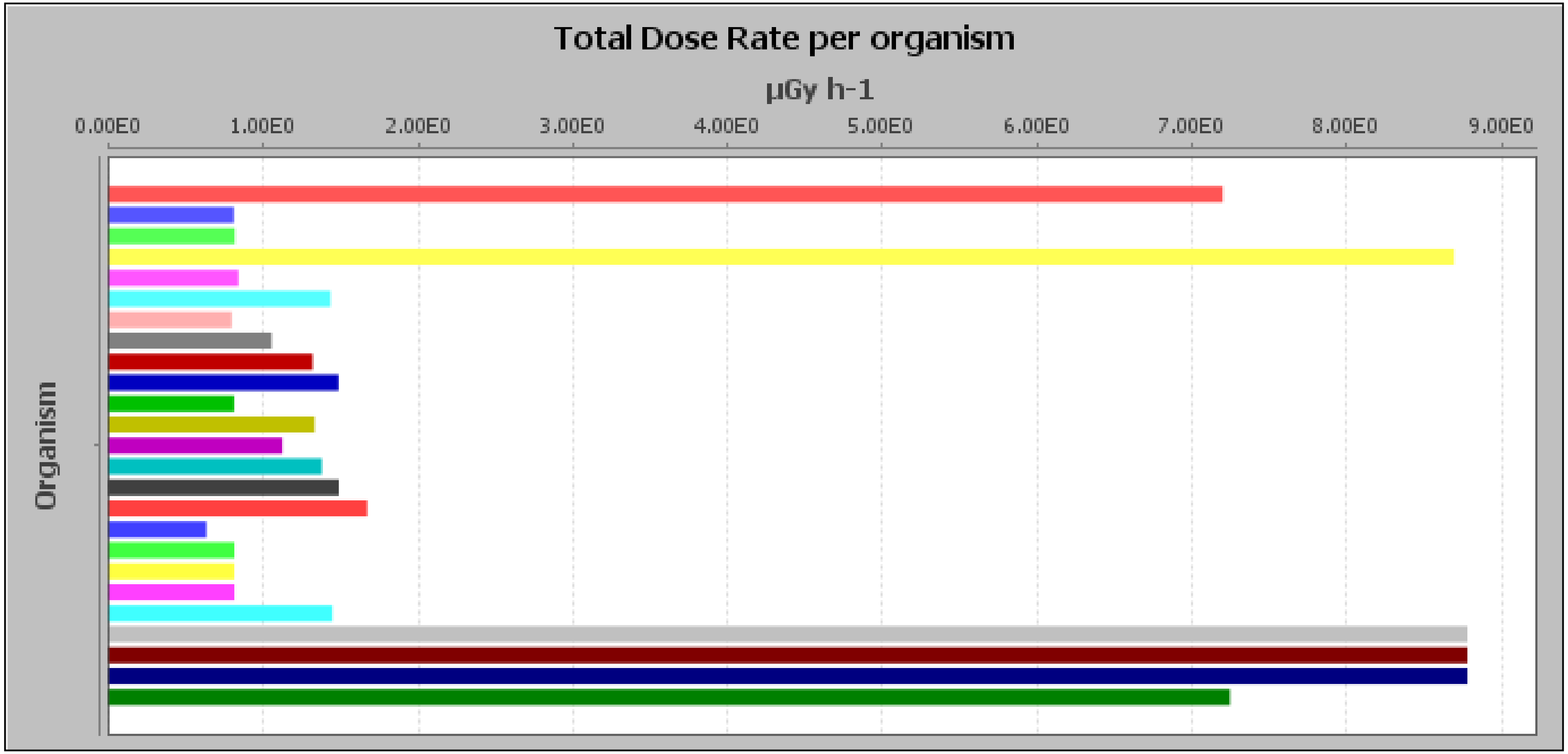
Calytrix Creswellii Shrub
Lepidosperma Lyonsii Grass
Pb-210
Po-210
Ra-226
Ra-228
Th-227
Th-228
Th-230
Th-232
U-235
U-238
Pa-231


Total Dose Rate per organism
µGy h-1
0.00E0
1.00E0
2.00E0
3.00E0
4.00E0
5.00E0
6.00E0
7.00E0
8.00E0
9.00E0
Organism

Radiation Assessments

RADIOLOGICAL RISK ASSESSMENT: WORKER DOSE ASSESSMENT

Company Name: TELLUS HOLDING
Document No.:
Date of Issue: 14 May 2016

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1	RADIOLOGICAL RISK ASSESSMENT: Worker Dose Assessment	Draft	14/05/2016	07/06/2016	HR

Prepared by:	Henriëtte Rossouw RSO Hygiea Consulting
Endorsed by:	

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1 INTRODUCTION

Hygiea Consulting was engaged by Tellus Holdings Ltd (the Proponent) to conduct a Human Health Risk Assessment (HHRA) on the workforce to assess the potential doses workers can receive as a result of their occupation at Sandy Ridge kaolin clay and waste storage facility (herein referred to as the 'Proposal' or the 'Facility').

The aim of the report is to provide a worker dose assessment . This report should be read in conjunction with the following reports

- *Sandy Ridge Project –Operating Strategy*
- *Radiological Risk Assessment- Fauna and Flora (ERICA)*
- *Radiological Risk Assessment- : Disposal of Radioactive Waste(RESRAD)*
- *Radiation Waste Management plan*
- *Waste acceptance criteria (WAC) developed for this facility is described in the waste acceptance criteria (document reference: TCO-5-05).*

1.1 BACKGROUND

The Proposal comprised of two main business components, mining of kaolin clay for export and storage and permanent isolation (disposal) of hazardous and intractable waste in mine voids.

The proposed commodity business involves mining kaolin mostly in an open cut methodology, processing on site and then exporting the kaolin via Fremantle Port to Asia where it will be used in various industrial sectors (e.g. paper, ceramics, fiberglass and paint). Kaolinite is a clay mineral also known as 'Kaolin clay', with the chemical composition $Al_2Si_2O_5(OH)_4$.

The waste aspect of the Proposal involves disposing of up to 100,000 tpa of intractable, hazardous and low level radioactive wastes in the mine voids (herein referred to as 'cells') over a 25 year period (i.e. 2,500,000 tonnes in total). Wastes would be accepted from across Australia.

Tellus will program the placement of waste into the disposal cell in based on the nature of the waste and planning of the cell layout to store waste of similar characteristics in designated areas of the cell. Radoioactive waste will be diposed of after chemical waste were placed in the cell.. To ensure optimisation of protection higher activity waste will be disposed of at the deeper end of the cell in a shaft and lower activity waste at the top. This further reduces the possibility of interactions between wastes of different types and ensure exposure to radioactive material is reduced

Cells would be filled in layers with multiple sections in each layer. Each layer would be divided into sections containing wastes of similar characteristics. Each section will be backfilled, compacted and all air pockets/voids excluded. Each layer will be compacted, until approximately 7m below the ground surface, where a thick capping layer of low permeability clay will be installed to prevent water ingress into the cell. Following this, more backfilling and a clay domed cap would be situated on the top of the cell, to shed any landing rainfall. During the waste disposal process, a roof canopy is positioned over the cell to exclude rainfall prior to the thick capping layer being installed.

Waste acceptance criteria (WAC) developed for this facility is described in the waste acceptance criteria (document reference: TCO-5-05). The radionuclide concentration limits is set taking into account the actual siting, design and planning of the facility (e.g. Natural geological barrier, arid climate, remoteness, engineered multi layered shielding and barriers, duration of institutional control, site specific management plans and operating procedures) and exposure dose constrains to ensure no person is exposed above the dose limit (as defined in Schedule I of the Radiation Safety (General) Regulations). These radioactive wastes are generally generated by medical research and industry, operation of research facilities (e.g. laboratory coats, overshoes, gloves), Naturally Occurring Radioactive Materials (NORMs), NORMs occurring on pipework and scale from industry, oil spills containing NORMs and orphan sources (i.e. gauges and instrumentation). Wastes which will not be disposed of into cells include: infectious materials, nuclear material, uncertified waste, putrescible waste and gases.

2 WORKER HEALTH RISK ASSESSMENT METHODOLOGY

The methodology followed the guidance given in the following documents:

- Environmental Health Risk Assessment-Guidelines for assessing human health risks from environmental Hazards. enHealth Council 2012
- Approved Procedure for Dose Assessment Guideline RSG05 Department of Industry and Resources.(DoIR)1997
- Managing naturally occurring radioactive material (NORM) in mining and mineral processing – Guideline, DMP (2010) NORM 5 Dose Assessment (UNDER REVIEW)
- Assessing Dose of the Representative Person for the Purpose of the Radiation Protection of the Public. ICRP Publication 101a. Ann. ICRP 36 (3). ICRP, 2006.

1.2 APPROACH

The risk assessment model was adopted in accordance with that specified in enHealth 2012. The key stages include:

- Issue identification.
- Hazard identification.
- Dose–response assessment.
- Exposure assessment.
- Risk characterisation.

Figure 1 display the relationship between the Human Health Risk Assessment (HHRA)process and Risk Management

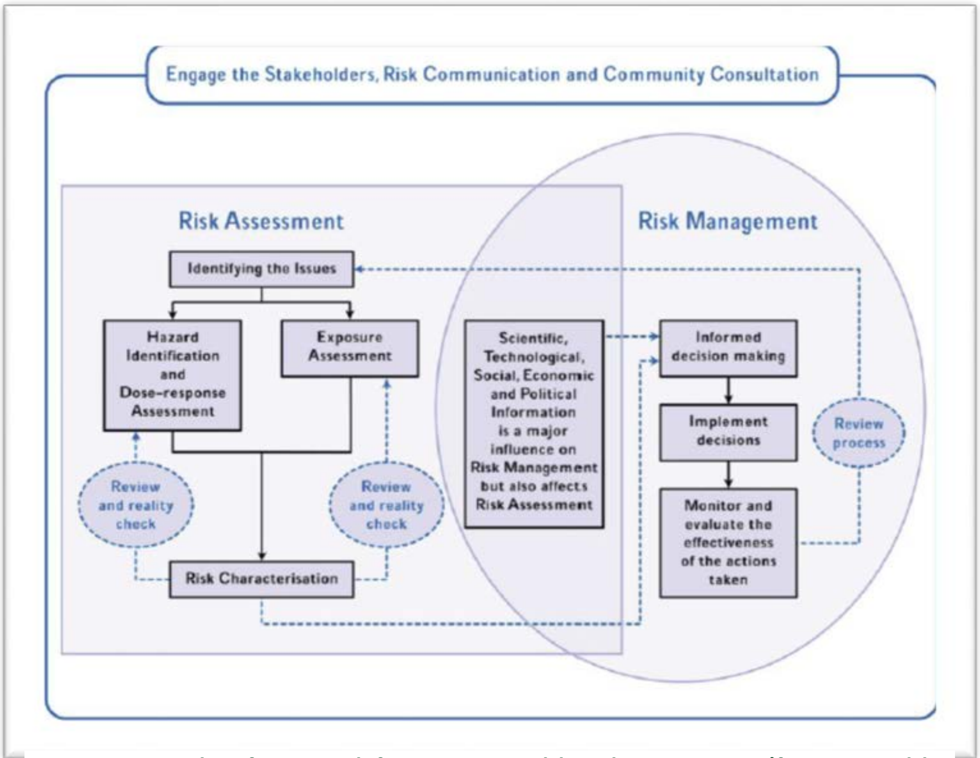

Figure 1: Australian framework for Human Health Risk Assessment (from enHealth 2004)

3 ISSUE IDENTIFICATION

Workers of the Proposal may be exposed to ionising radiation as a result of the handling and disposal of LLW . By assessing the potential exposure the proposal can identify the highest risk employment groups and tasks and ensure that correct controls are in place so that the exposure is within dose constrain limits (>5 millisievert per annum (mSv/a)).Those controls are discussed in the waste management plan. It also serves to cofirm that the WAC is suitable to ensure no over exposure of the workforce will occure

1.3 IONIZING RADIATION AND HEALTH

The majority of risks associated with radiation are known and have been quantified. There have been many large scale studies worldwide of cancer risk in people arising from radiation exposure. While there is a possible increased risk of cancer and hereditary effects at low radiation doses or for radiation delivered over a long period of time, these effects are not always detectable in scientific studies. However, their likelihood increases as dose increases.(ICRP,2007)

The objective of radiation protection is to limit human exposure by the application of comprehensive programs that measure all significant radiation sources.
Where it is expected that a worker will be exposed to radiation as a result of their employment, they must not be exposed above prescribed dose limits. In Australia, these dose limits are prescribed in the *Recommendations for Limiting Exposure to Ionizing Radiation (1995)* and *National Standard for Limiting Occupational Exposure to Ionizing Radiation (2002), Radiation Protection Series No. 1* which reflects international best practice in radiation protection.

Harmful tissue reactions (acute or deterministic effects) occur when doses are high (greater than 500 mSv). These effects occur shortly after exposure (minutes to weeks) and can include sterility, skin burns and acute radiation syndrome. Death can occur at very high doses(10 000 mSv) (ARPANSA Fact Sheet – Ionising Radiation and Health)

The current limit of occupational radiation exposure is 20 mSv/a averaged over 5 years, and not more than 50 mSv received in any one year. This dose limit only applies to radiation exposure received occupationally, and does not include exposures from natural background radiation or medical doses. The dose limit for members of the public is 1 mSv/a.

The ARPANSA Regulatory Guide (ARPASA 2014) state that In the process of developing the safety case the applicant must propose a dose constraint for workers, below which protection will be optimised, in accordance with the national standard RPS No. 1 Recommendations for Limiting Exposure to Ionizing Radiation (1995) and National Standard for Limiting Occupational Exposure to Ionizing Radiation (republished 2002) and which would not exceed 5 mSv/a

1.4 RADIATION WASTE SOURCES

The types and form of radioactive waste that are likely to be managed at the facility would be generated from:

- Medical research and industry (use of radioisotopes and sealed radioactive sources which generate very low levels of activity concentrations).
- Mining and processing of mineral ores or other material containing NORMS such as phosphate minerals, mineral sands, coal, some gold bearing rocks and hydrocarbons. These generally contain long lived radionuclides at relatively low concentrations. However, NORMS such as scales arising in the oil and gas industry may have higher activity concentration levels but would still be categorised as low level wastes.
- Intervention actions, which are necessary after accidents or to remediate areas affected by past practices
- Disposal of disused sealed radioactive sources (including orphan sources).

Sandy Ridge is seeking approval to operate as a near surface geological repository. It will not operate as a deep geological repository and therefore, only Low Level Radioactive Waste (LLRW) can be accepted. Under no circumstances can the Facility accept High Level Radioactive Waste (HLRW) .

1.5 WASTE ACCEPTANCE LEVELS

Waste acceptance criteria (WAC) developed for this facility is described in the waste acceptance criteria (document reference: TCO-5-05). The radionuclide concentration limits is set taking into account the actual siting, design and planning of the facility (e.g. Natural geological barrier, arid climate, remoteness, engineered multi layered shielding and barriers, duration of institutional control, site specific management plans and operating procedures) and exposure dose constrains to ensure no person is exposed above the dose limit (as defined in Schedule I of the Radiation Safety (General) Regulations).

These radioactive wastes are generally generated by medical research and industry, operation of research facilities (e.g. laboratory coats, overshoes, gloves), Naturally Occurring Radioactive Materials (NORMs), NORMs occurring on pipework and scale from industry, oil spills containing NORMs and orphan sources (i.e. gauges and instrumentation). Wastes which will not be disposed of into cells include: infectious materials, nuclear material, uncertified waste, putrescible waste and gases.

4 EXPOSURE ASSESSMENT

1.6 POTENTIAL WORKER EXPOSURE PARAMETERS

Several possible pathways of radiation exposure were considered and assessed whether they are relevant to the exposure of the sensitive receptors as discussed in Table 1.

Table 1: Exposure pathways

Potential Worker Exposure Pathways	Relevant	Comment
External radiation exposure (γ-radiation)	Yes	Possibility due to nature of radioactive materials.
Inhalation of suspended dust (α-radiation)	Yes	Possible but unlikely due to control methods in place when handling NORM type waste
Ingestion of drinking water (α- and β-radiation)	No	All drinking water at operations and in surrounding areas is provided from separate water supplies. No reliant natural water source near facility. Therefore, any exposure due to the ingestion of drinking water could not be attributed to the site activities.
Incidental ingestion of dust and soil	No	Not considered applicable.
Surface contamination	No	Not considered applicable.
Inhalation of radon and decay products	Yes	Similar facilities indicate very low risk of inhalation of radon products due to nature of waste disposed, the proposed containment methods and the half-life of Radon. Included where relevant.
Ingestion of home grown produce or gathered bush food	No	Phase one and phase two flora studies indicate no local bush food consumption in area. Details are provided in the PER.
Ingestion of meat, milk or locally caught fish	No	Not considered because of the arid nature of location and the unlikelihood of these activities happening.

1.7 WORKFORCE SIMILAR EXPOSURE GROUPS

The following work categories and numbers of workers are planned (Table 2). Workers are placed in Similar Exposure Groups (SEG's) to ease assessment.

Table 2: Workforce information

Workforce SEG's	Description
Transport	Transport of workers is not part of the Tellus workforce and would be arranged by client.
Radiation waste receipt and storage	Workers involved in the unloading, inspection, and storage (warehouse) of radioactive waste.
Waste packaging	Workers involved in the packaging of radioactive waste for disposal (cementing and concreting).
Waste placement/burial	Unloading and burial of radioactive waste.
Chemical waste placement	Backfill of cell with chemical wastes and inert fill.
Earthmoving and contouring	Capping and closure of cell.
Administration and other staff	Supervisors, admin, security and other non-exposed workers.

1.8 ASSUMPTIONS

1.8.1 EXPOSURE HOURS

With uncertainty of how much radiation waste will be sent to the Facility for disposal the following exposure hours were assumed based on current market expectations (Table 3).

Table 3: Exposure hours

Workforce SEG's	Assumed hours per year	Logic of assumed hours
Radiation waste receipt and storage	1000	Unknown. Assume 1000 hours.
Waste Packaging	160	4 packing campaigns a year of 5 days each.
Waste placement/ burial	80	Actual radioactive waste handling component to take 20 hours max per campaign. Assuming 4 campaigns a year.
Chemical waste placement	1920	Full shift assumed.
Earthmoving and contouring	882	3 months.
Admin and other staff	2000	Assuming maximum.

1.8.2 GAMMA EXPOSURE

The following exposure levels were assumed based on similar facilities exposure records (Table 4).

Table 4: Exposure hours

Workforce SEG's	µSv/hr expected dose
Radiation waste receipt and storage	0.4
Waste Packaging	0.6
Waste placement/burial	0.05
Chemical waste placement	0.05
Earthmoving and contouring	0.05
Admin and other staff	0

1.8.3 INHALATION OF SUSPENDED DUST

There is a risk of exposure due to inhalation of dust during the packaging and handling of NORM waste. Drawing from experience and data from the mining and the oil and gas industry, the following values (Table 5) were assumed and are very conservative. The volume and the way waste would be packaged, as well as onsite procedural controls, would safeguard levels exceeding those shown in Table 5.

Table 5: Assumed dust ad concentration levels

Value	Average dust concentration mg/m^3	Average dust activity mBq/m^3
Ave	0.085	0.330

1.8.4 INHALATION OF RADON AND DECAY PRODUCTS

Similar facilities indicate very low risk of inhalation of Radon products due to the nature of waste disposed, the containment thereof and, the half-life of Radon. For the purpose of this assessment, it has been assumed the dose due to inhalation of Radon gas will be less than 0.004mSv/a.

1.9 INITIAL EXPOSURE ASSESSMENT

Based on the Approved Procedure for Dose Assessment (Guideline RSG05 Department of Industry and Resources. (DoIR)1997) the following doses were calculated for each workgroup (Table 6).

Table 6:Dose calculations for each workgroup per year

Workforce SEG's	Gamma dose (mSv/a)	Individual Internal Dose (mSv/a)	Inhalation of RnDP (mSv/a)	Total dose (mSv/a)
Rad waste receipt and storage	0.400	0.014	0.004	0.418
Waste packaging	0.096	0.002	0.004	0.102
Waste placement/burial	0.004	0.001	0.004	0.009
Chemical waste placement	0.096	0.000	0.000	0.096
Earthmoving and contouring	0.044	0.000	0.000	0.044
Admin and other staff	0.000	0.000	0.000	0.000

All of the workforce SEGS exposure is well below the occupational exposure limit of 10 mSv/a , the dose constrain level of 5mSv and are unlikely to be exposed above the public dose limit of 1msv/a.

Investigation into exposure levels from similar international facilities indicate that approximately 95% of the staff receive a dose less than 0.1 mSv/a, and 80 % less than 0.01 mSv/a. The exposure times at the international facility would be longer that those assumed as Sandy Ridge due to the amount of waste disposed. These levels are within similar range of those calculated above.

1.10 SENSITIVITY ANALYSIS ON ASSUMED VALUES

Sensitivity analysis (varying one-parameter-at-a-time) was conducted on the assumed variables within the dose assessment to determine how sensitive the modelled dose to a human receptor is to variations in the selected parameter. This analysis was carried out after the regular calculations were completed by taking each assumed parameter selected and repeating the calculation with the parameter under test set at a 50 % and a 100 % increase. Only a single test parameter is varied at a time.

The sensitivity of the parameters listed below was increased to determine the effect on the total dose calculated.

- *Assumed hours.*
- *Gamma Dose Rate.*
- *Dust Activity concentration.*

Figure 2 illustrated the effect of a 50 % and 100 % increase in the exposure time. Even with a 100 % increase in exposure time, the exposure levels will still be below the public exposure level of 1 mSv/a.

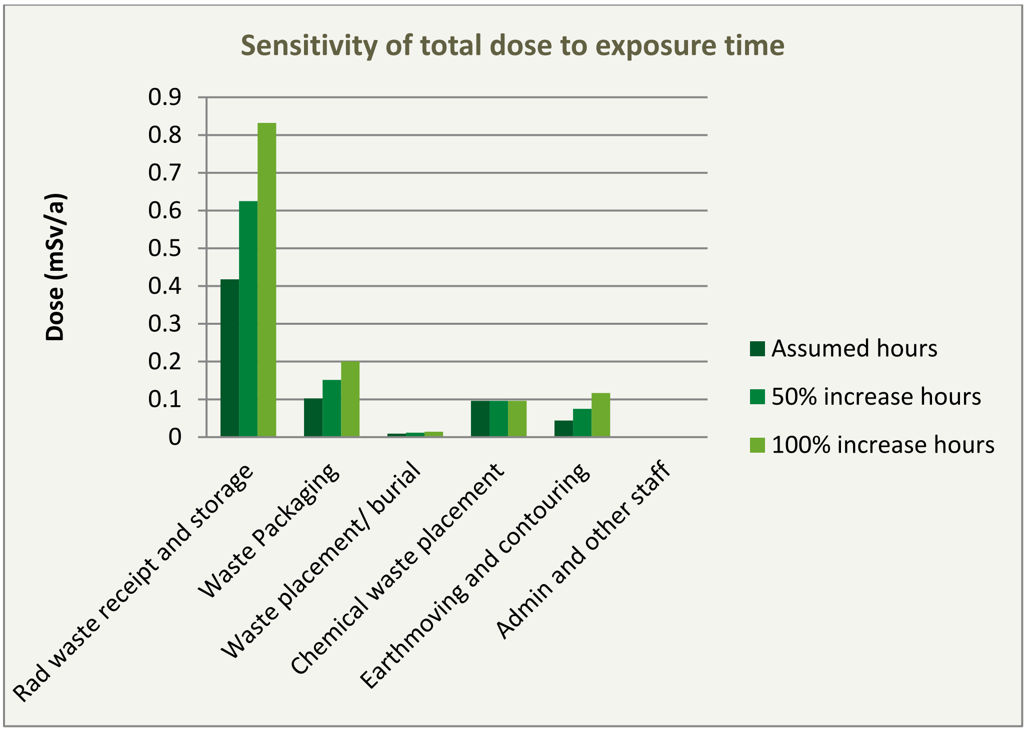

Figure 2: Sensitivity of dose to exposure time

The effect of dose rate being 50 % and 100 % greater than was assumed in the base calculations was also tested. Figure 3 shows that even with a 100 % increase in the dose rate no exposure calculated were above the public exposure limit of 1 mSv/a

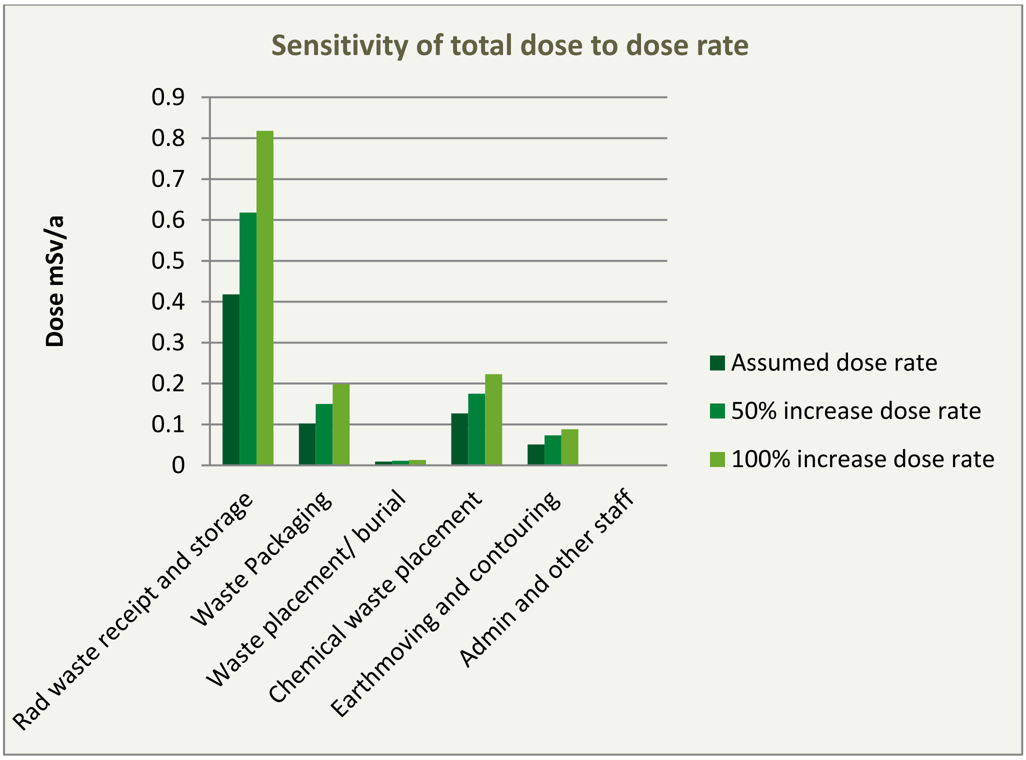

Figure 3: Sensitivity of dose to dose rate

Sensitivity analysis on the dose received if the activity concentration of the dust is 50 % and 100 % higher than was assumed in base calculation was conducted to test what effect it would have on the total dose. As indicated in Figure 4, all results were below the public exposure limit of 1 mSv/a.

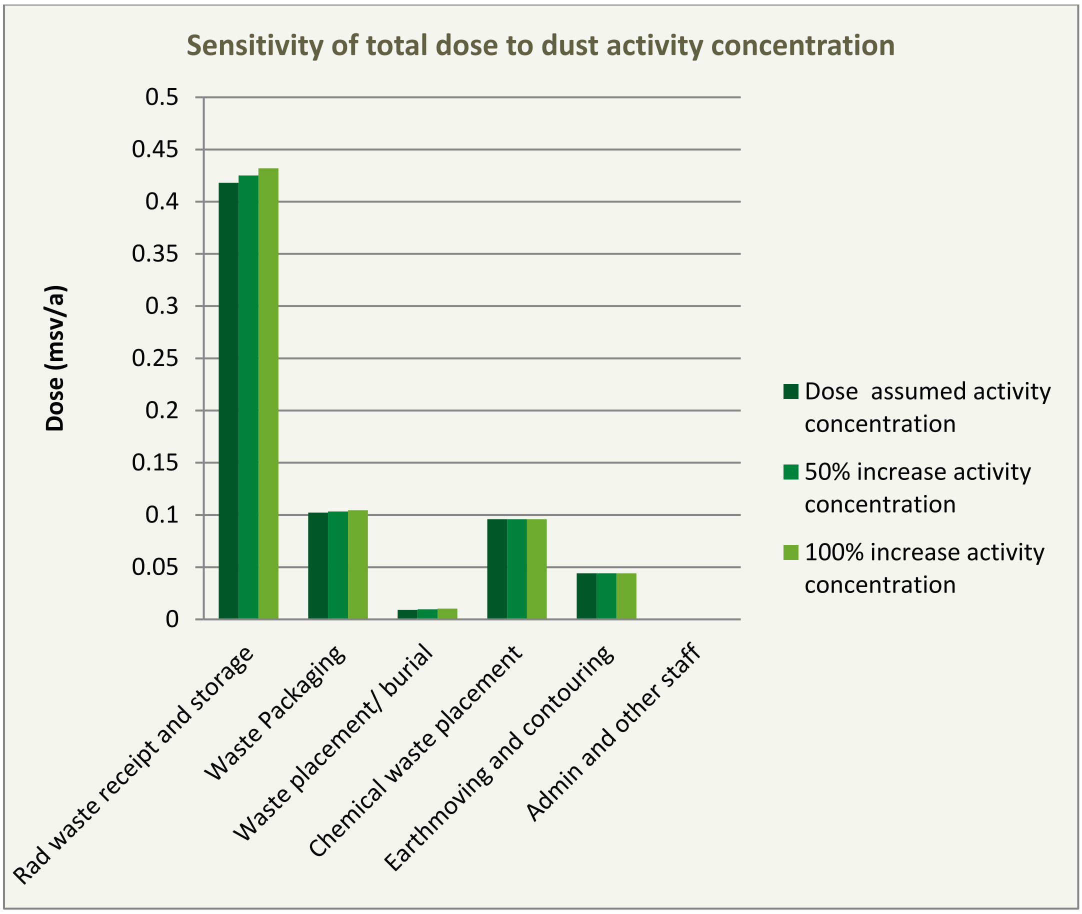

Figure 4: Sensitivity of total dose to dust activity concentration

5 RISK CHARACTERISATION AND RECOMMENDED CONTROLS

The Risk associated with each SEG exposure are summarised below and a brief description of controls that will be implemented to ensure the dose to workers is as low as reasonably practicable. These controls are discussed I ore details in the radiation management plan

1.11 TRANSPORT

Workers involved in the transport of radioactive material to site can be exposed to external gamma radiation from the waste package, Inhalation of suspended dust (α- radiation) And Inhalation of radon and decay products. (Calytrix Consulting (2013). Transport will be arranged by the client and all exposure assessments should be addressed in the clients transport management plan and emergency procedures. The Proponent requires that all packages that arrive on site must be transported in accordance with requirements of the Australian Code of Practice for the Safe Transport of Radioactive Material that adopts International Atomic Energy Agency (IAEA) Transport Safety Regulations.

1.12 RADIATION WASTE RECEIPT AND STORAGE

Workers involved in the unloading, inspection, and storage (warehouse) of radioactive waste can be exposed to external gamma radiation from the waste package, Inhalation of suspended dust (α- radiation) and Inhalation of radon and decay products. Dose assessment results indicate that exposure is very dependent on the duration of exposure. It was assessed that workers are unlikely to be exposed above 0.4 mSv/a Worst case scenario assessment (double the exposure time that is considered realistic) indicate that levels are unlikely to be above 1mSv/a.

Controls that will be implemented to ensure workers are not exposed to levels above the dose constraints include screening of waste packages on arrival to ensure the radiation levels (alpha beta and gamma) is within acceptable (as specified in the transport code) and safe levels, wearing of electronic dosimeters to determine exposure levels, Ensuring packages are not damaged on arrival, dust controls if bulk material are handled and PPE if required.

1.13 WASTE PACKAGING

Workers involved in the packaging of radioactive waste for disposal (cementing and concreting) can be exposed to external gamma radiation from the waste package, Inhalation of suspended dust (α- radiation) and Inhalation of radon and decay products. Dose assessment results indicate that exposure is very dependent on the duration of exposure. It was assessed that workers are unlikely to be exposed above 0.1 mSv/a. Worst case scenario assessment (double the exposure time that is considered realistic) indicate that levels are unlikely to be above 0.2 mSv/a.

Controls include packaging within a well ventilated designated area, all workers coming into close proximity to the radioactive waste shall wear personal radiation monitors, limiting the time workers spend packaging, increasing the distance between workers packaging the waste and sources, and shielding.

1.14 WASTE PLACEMENT/BURIAL

Workers involved in the unloading and burial of radioactive waste may be exposed to low levels of external gamma radiation from the waste package, Inhalation of suspended dust (α-radiation) and Inhalation of radon and decay products. The waste at this stage is packaged and will be lowered into the shafts by mobile equipment. Workers protection include shielding (provided by the waste packaging and mobile equipment), increase in distance from sources by using mobile equipment and scheduling of waste placement to ensure minimum time is spend near radioactive waste.

Exposure from this SEG is expected to be below 0.01msv/a

1.15 CHEMICAL WASTE PLACEMENT

Workers involved in the unloading and burial of chemical waste may be exposed to low levels of external gamma radiation from the waste package, Workers protection include shielding (provided by the waste packaging, the radiation shaft and mobile equipment), increase in distance from sources by using mobile equipment and scheduling of waste placement to ensure minimum time is spend near radioactive waste.

Exposure from this SEG is expected to be below 0.1msv/a.

1.16 EARTHMOVING AND CONTOURING

Earthmoving and contouring SEG workers are tasked with the capping and closure of cell. They may be exposed to low levels of gamma radiation from the waste cell while cap is constructed. Dosage of this SEG is expected to be below 0.05mSv/a.

1.17 ADMINISTRATION AND OTHER STAFF

No Radiation dose above background is expected to occur in this SEG

6 CONCLUSION

All radiation exposure hazards identified during the baseline qualitative risk assessment were assessed against likelihood of exposure above the exposure limits (20 mSv/a) and above a dose constrain limit of 5mSv.

Even with an increase of 100 % higher than those assumed in the baseline calculations, no dose were above 1 mSv/a. Investigation into exposure levels from similar international facilities indicate that the most exposed worker was around 1.2 mSv/a (individual in charge of traveling crane operations above the disposal vaults). It is therefore unlikely that any person will be exposed to doses above 1.2 mSv/a

On the basis of the characteristics described above, the initial dose assessments and sensitivity analysis concludes that it is highly unlikely that workers will be exposed to levels above the dose constrain limit of 5 mSv/a . Risks from exposure would be further reduced by following standard guidelines and procedures for the transport and handling of dangerous and hazardous goods. In addition, the separation of low level radioactive wastes from other wastes, in appropriately designed pits, would further reduce the risks of exposure at the proposed Sandy Ridge Facility.

2 GLOSSARY OF TERMS

Absorbed dose	means the energy transferred from radiation to unit mass of the exposed matter. The unit used to describe absorbed dose is the gray (Gy);
Activity	the activity of a radioactive source is the number of atoms that are disintegrating per second, measured as Becquerels
ALARA	As low as reasonably achievable, taking into account social and economic factors
Alpha particle	Alpha particles are electrically charged helium atoms, ejected at very high speed (30 000 km/s) from the atom at the instant of breakdown. They are slowed and stopped by about the thickness of a sheet of paper or by about 3 cm of air. Alpha particles cannot get through the dead outer layer of the skin, but they make a dense ionization trail along their stopping track, so they can produce damage to biological tissue, if emitted inside the body following ingestion or inhalation. An alpha particle does not travel far in air before picking up free electrons and turning into an atom of inert helium.
Becquerel (bq)	One atom decaying (disintegrating) per second
Beta particle	Beta particles are electrons formed by the conversion of a neutron into a proton, and are emitted by the atom at nearly the speed of light (300 000 km/s). They can travel a few centimetres in solids and a few metres in air before stopping, but carry less energy, and give it up in track that is more spread-out and less dense than that of alpha particles (so the damage to human tissue is very much less).
Controlled area	means an area to which access is subject to control and in which workers are required to follow specific procedures aimed at controlling exposure to radiation
Contractor	means a person who under a contract performs work or supplies a service in connection with a mining activity on a mining site
Dose	means a measure of the radiation received or ‘absorbed’ by a target. For the purpose of this document reference to dose is a reference to effective dose

Effective dose	means the weighted sum of all the equivalent doses in all the tissues and organs of the body. The weighting ensures that the detriment is equal whether or not the whole body is irradiated uniformly. The units used to describe effective dose is the Sievert (Sv)
Equivalent dose	means a measure of the dose to a tissue or organ that expresses all radiation doses on a common biological scale. It is the product obtained by multiplying the average absorbed dose in the tissue or organ by a radiation weighting factor to account for the different potential for injury of different types of radiation
Emanation rate	The rate of release of radon from a solid surface area with units of Bq/(m^2.s)
Emanating power	The rate of release of radon from a broken material volume with units of Bq/(m^3.s)
Gamma ray or radiation	Gamma rays are electromagnetic energy, like x-rays, are very penetrating, and pass with some reduction in intensity through many centimetres of solids. Gamma exposure reduces with the inverse square of distance to the point source.
LLα or LLA	Long lived alpha emitters (dose from which is measured as mSv/a) means the presence in airborne dust of any of the alpha particle emitting radionuclides in the uranium decay series, except for those
mSv	Unit used to describe effective dose is the Sievert (Sv). Frequently used SI multiples are the millisievert (1 mSv = 10^{-3} Sv = 0.001 Sv) and microsievert (1 μSv = 10^{-6} Sv = 0.000001 Sv
Personal radiation dosimeters	Thermo-Luminescent Dosimeters, electronic dosimeters, Optical Stimulation Dosimeters, film badges, or quartz fibre electroscopes
Radiation	means ionizing radiation, that is electromagnetic or corpuscular radiation capable of producing ions directly or indirectly in its passage through matter
Radon (rn)	Radon (gas), the only decay product in the chain between uranium and lead which is a gas at standard temperature and pressure. It decays to lead via intermediaries called Radon daughters.
Reasonably practicable	Whether particular risk management measures are reasonably practicable (as defined by Section 5 of the Workplace Health and Safety Act 2007) is to be decided with regard to:

(a) the likelihood that the risk could result in injury; and

(b) the seriousness of any injury that could result from realisation of the risk; and

(c) the availability, suitability, effectiveness and cost of the measures; and

(d) any other relevant factors.

RnP	Unstable isotopes of polonium, bismuth and lead (Po218, Pb214, Bi214, Po214) produced during decay of radon gas (hence “radon daughters or progeny”). Their concentration is measured in terms of their PAEC. Radon progeny are charged particles and attach strongly to any nearby surface. The radon progeny of concern have short half-lives and therefore, if inhaled, attach to the walls of the lungs and decay rapidly before the normal lung clearance mechanisms can expel them. When radon progeny decay, they give off alpha, beta and/or gamma radiation.

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Radiation Assessments

TELLUS

RADIATION RISK ASSESSMENT-POST CLOSURE

SANDY RIDGE FACILITY

Company Name: Tellus Holdings Ltd
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1	RADIOLOGICAL RISK ASSESSMENT: POST CLOSURE	Draft	08/08/2016		HR

Prepared by:	Henriëtte Rossouw RSO Hygiea Consulting
Endorsed by:	

Executive summary

Tellus Holdings Ltd (Tellus) proposes to construct and operate a dual revenue Kaolin (clay) mine and waste facility, accepting Class IV (Secure Landfill) and Class V (Intractable Landfill) waste (the Proposal). The waste aspect of the Proposal involves storage or permanent isolation of up to 100,000 tonnes per annum (tpa) of intractable, hazardous and low level radioactive wastes in the mine voids (referred to as 'cells') over a 25 year period (i.e. up to 2,500,000 tonnes of wastes in total).

The properties of radioactive wastes vary, not only in terms of radioactive content and activity concentration but also in terms of their physical and chemical properties. A common characteristic of all radioactive waste is its potential to present a hazard to people and to the environment, and it must therefore, be managed so as to reduce any associated risk to acceptable levels. The preferred strategy for the management of all radioactive waste is to contain it (i.e. to confine the radionuclides to within the waste matrix, the packaging and the disposal facility) and to permanently isolate it from the environment. Materials would be stored in an arid environment, near surface, geological repository using a "best practice" storage and isolation approach underpinned by a safety case.

The primary design goal of a radioactive waste disposal facility is to provide for the protection of human health and the environment during the operation of the facility and in the longer term, after the facility is closed and until the time when the associated radiological hazard will reach an insignificant level through natural decay. This report deals specifically with the post-closure period of the facility and in particular the human intrusion scenarios during the period of passive safety

The dose limit for members of the public from all sources during operations is an effective dose of 1 mSv in a year. During the period of passive safety after closure a risk target approach is used and this should be considered as the target criteria not to be exceeded. To comply with the risk target during the passive safety period the waste disposal facility and management systems are designed so that the estimated average dose or risk to members of the public, who may be exposed as a result of the disposal facility in the future, shall not exceed a dose constraint of 0.3 mSv in year[1]. As well as considering passive safety where the disposal system evolves and performs as expected, consideration has been given to human intrusion, this report looks in particular at this. As human intrusion bypasses the designed barriers a dose constraint of 0.3mSv per year is not felt to be appropriate. ARPANSA[2] advise where it is calculated that human intrusion could result in doses of between 10 and 100 mSv for any human associated with the intrusion, there needs to be further evaluation of the scenario producing this result. Tellus has used a dose of 10mSv/yr. to asses a number of the human intrusion scenarios analysed.

An assessment has been undertaken, with the intention of estimating the post closure radiological effects that waste material could have on humans who may unknowingly be exposed to the radiation hazards on the site. The Assessment took into

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[1] IAEA-TECDOC-1380 Section 3.3.2
[2] Australian Radiation Protection and Nuclear Safety Agency – Licencing of Radioactive Waste Storage and Disposal facilities Section 3.3.5

consideration relevant pathways of exposure during the post closure period, to demonstrate that potential radiological impacts are at acceptable level of risk against set dose constrain levels to adequately safeguard humans.

This assessment was undertaken using both first principle calculations and RESRAD modelling software.

Five post-closure exposure scenarios were investigated:

1. Scenario 1 – First Principle evaluation of human intrusion next to the shaft containing (Category B) sealed radioactive sources that is in accordance to the waste acceptance criteria.

2. Scenario 2 – RESRAD evaluation of human intrusion - living on exposed bulk waste at activity concentration levels of Category A.

3. Scenario 3 – RESRAD evaluation of human intrusion - living on exposed bulk waste at activity concentration levels of Category C.

4. Scenario 4 – RESRAD evaluation of a recreational visitor to the site post closure.

5. Scenario 5 – A “reverse calculation” using RESRAD evaluation to determine radionuclide activity concentration levels in bulk NORM wastes which would give rise to tolerable exposure conditions for post closure and intrusion scenarios.

Scenario 1 results demonstrated the shielding provided is sufficient to shield the radiation from all sources assessed except high activity Caesium-137 sources. With an assumed 40 hours exposure the dose is 0.63mSv. Given the highly conservative nature of the assessment and the low probability of such an event occurring it can be concluded that the risk is sufficiently controlled.

The results from Scenarios 2 and 3, demonstrated in the unlikely case where humans would reside on top of exposed bulk waste of category A, an exposure of 587 hours / year could result in total maximum dose of 10 mSv/y. If the exposure were to occur on uncapped Category C waste, 6.5 hours occupancy would result in total maximum dose of 10 mSv/y. It is implausible that someone would spend this duration in the bulk waste due to site selection of the facility and the cap design. The long term (10,000 plus years) performance of the cap has been modelled using both near-surface hydrogeological and erosion modelling software. The modelling has confirmed that the cap design and site selection is robust from both water infiltration and erosion so the only way such an exposure could occur would be for example during an archaeological dig.

From the analysis of Scenario 4 it was shown that a maximum total dose of 6.2×10^{-7} mSv/y is incurred only at 100,000 years after closure, indicating that for the expected land-use post institutional control, no risk to human receptors are foreseen, given that the possibility of intrusion is mitigated through engineering controls.

In Scenario 5 the RESRAD (Onsite) code was also used, to determine radionuclide activity concentration levels in bulk NORM wastes which would give rise to conditions as specified above for post closure and intrusion scenarios. These values were adopted in the WAC for NORM waste.

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1 INTRODUCTION

1.1 BACKGROUND

Tellus is planning to develop the Sandy Ridge Project (the Proposal). The Proposal is comprised of two main business components, mining of kaolin clay for export and storage and permanent isolation (disposal) of hazardous and intractable waste in mine voids which will function as a near surface, arid area geological repository.

The waste aspect of the Proposal involves storage or permanent isolation of up to 100,000 tpa of intractable, hazardous and low level radioactive wastes in the mine voids (herein referred to as 'cells') over a 25 year period (i.e. up to 2,500,000 tonnes in total). Wastes would be accepted from across Australia.

Waste acceptance criteria (WAC) developed for this facility is described in the Tellus Waste Acceptance Criteria (document reference: TCO-5-05-002). The radionuclide concentration limits is set taking into account the actual siting, design and planning of the facility (e.g. natural geological barrier, arid climate, remoteness, engineered multi layered shielding and barriers, duration of institutional control, site specific management plans and operating procedures) and exposure dose constraints to ensure no person is exposed above the dose limit (as defined in Schedule I of the Radiation Safety (General) Regulations). These radioactive wastes are generally generated by medical research and industry, operation of research facilities (e.g. laboratory coats, overshoes, gloves), Naturally Occurring Radioactive Materials (NORM), NORM occurring on pipework and scale from industry, oil spills containing NORMs and orphan sources (i.e. gauges and instrumentation). Wastes which will not be disposed of into cells include: infectious materials, nuclear material, uncertified waste, putrescible waste and gases.

The properties of radioactive waste vary, not only in terms of radioactive content and activity concentration but also in terms of physical and chemical properties. A common characteristic of all radioactive waste is its potential to present a hazard to people and to the environment, and it must therefore be managed so as to reduce any associated risk to acceptable levels. The preferred strategy for the management of all radioactive waste is to contain it (i.e. to confine the radionuclides to within the waste matrix, the packaging and the disposal facility) and to permanently isolate it from the environment. Near-surface disposal of low level waste (LLW), at varying depths down to about 30 metres below ground surface, has been practiced internationally for over 20 years.

The radiological impact to humans and the environment from the disposal of radioactive waste are kept to acceptable levels by:

- Use of appropriate site selection criteria- an arid environment, near surface, geological repository.
- Appropriate design, construction and operation of the waste disposal facility.
- Establishment of limits upon radionuclide concentrations in the waste based on the approach that there is unrestricted access following a period of institutional control.
- Specification of qualitative criteria for the physical and chemical properties of waste and additional criteria on waste packaging and conditioning which ensures that the release of radionuclides from the site is minimised.
- Comprehensive safety assessment of the disposal site and disposal facility design.

Tellus operations are underpinned by utilising a combination of engineered and natural barriers, known as a multi barrier system, which provides long term containment and isolation of the waste.

Cells would be filled in layers with multiple sections in each layer. Each layer would be divided into sections containing wastes of similar characteristics.

After the placement of waste in the cell has been completed, the following protection measures will be implemented:

- An all-weather cover will be maintained over the cell until it is backfilled and capped to allow for protection from all weather conditions, without the possibility of creating leachates or contaminated surface water.
- Any airspace surrounding the placed waste will be backfilled with kaolin processing plant waste product (low value kaolin and quartz sand) or kaolinised granite overburden to fill all void space and provide stability.
- The cell will then be backfilled with compacted clay, silcrete, and laterite.
- The surface of the cell will be covered with a domed clay cap to exclude rainwater.

After a 10 year period of subsidence and environmental monitoring to confirm the stability and integrity of the cell, further kaolinised granite and soil will be placed over the cap and the area re-vegetated with species of local provenance. Local species would be selected based on their root system penetration (depth), ensuring that the capping design is not compromised.

Tellus will monitor and manage the site for an extended period following closure before returning ownership to the State, a period termed institutional control. The institutional control period (ICP) will ensure the wastes stored and disposed of in the geological repository are undisturbed for a period of time until they no longer pose a risk to human health and the local environment.

Further information on management of the Facility is provided in the Radiation Waste Management Plan.

1.2 SCOPE AND OBJECTIVES

The primary design goal of the Proposal is to provide for the protection of human health and the environment in the long term, after the facility is closed and until the time when the associated radiological hazard will reach an insignificant level.

The dose limit for members of the public from all sources is an effective dose of 1 mSv in a year, and this, or its risk equivalent, should be considered as criteria not to be exceeded in the future. To comply with this limit, the Proposal is designed so that the estimated average dose or risk to members of the public, who may be exposed as a result of the disposal facility in the future, shall not exceed a dose constraint level of 0.3 mSv in a year.

This assessment has been undertaken to estimating the radiological effects, post closure that disposed waste material could have on the environment and members of the public. This includes all relevant pathway of exposure and demonstrate that potential radiological impacts are within the dose constrain limits and manageable to adequately safeguard humans.

2 SITE GEOGRAPHICAL CONTEXT

The Proposal is located approximately 75 kilometres (km) north-east of Koolyanobbing, Western Australia. Access is via a 100 km road to the Mt Walton East Intractable Waste Disposal Facility (IWDF) that extends northward from the Boorabbin Siding on Great Eastern Highway; a new 4.5 km westwards section, and a 5.3 km northwards section of new site access road into the development envelope (Figure 1).

There are no sensitive receptors within 50 km of the location of the Proposal. The nearest operation is the Class V IWDF (Intractable Waste Disposal Facility) Mount Walton East located approximately 6 km to the East, which operates on a campaign basis and does not have permanent residents. The nearest mining camp is the Carina Iron Ore Mine Accommodation Camp located approximately 52 km to the South-East of Sandy Ridge.

The location of the Sandy Ridge Project has been specifically chosen to meet the requirements of International and National codes relating to the siting of a near surface geological repository. These site characteristics include:

- Geologically stable — the development envelope sits within the Archean Yilgarn Block and is geologically typical of areas overlying deeply weathered granite domes. It has very low seismicity (no earthquakes have been recorded at Sandy Ridge) and no volcanic or tectonic activity.
- Natural geological barrier — the kaolinised granite is laterally extensive (160 km long and 20 km wide), has been stable for at least 20 million years and is typically 30 to 50 m thick. This is capped by erosion resistant silcrete and laterite layers typically 4 to 6 metres thick in total, overlain by yellow clayey sand.
- Semi-arid desert Mediterranean climate — averages just over 250 mm of rainfall per annum and evaporation is greater than 2,000 mm per annum. This means very little rainfall occurs across the site and all water will evaporate before it infiltrates beyond 4 to 6 m depth.
- No surface water receptors - there are no channels or creeks in the development envelope.
- Very little (if any) surface water runoff – Due to the low rainfall, high evaporation, permeable upper soil profile and gently sloping topography, significant rainfall events infiltrate quickly to shallow depths before being evaporated. There is a low likelihood of surface flows in the local catchments and any flows are short-lived and local in nature.
- Lack of commercial mineral deposits – there is no evidence to suggest that there is potential for economic mineral or hydrocarbon deposits beneath the kaolin deposit.
- Topography – the development envelope is flat to gently undulating and suitable for the construction of infrastructure and heavy vehicle movement.
- Absence of Population – located in an area with no population, the nearest population centre is a non-permanent mining camp approximately 52 km away.
- Agricultural land use – there is no potential for medium to high value agriculture.
- Environmental values – there will not be any adverse impact to conservation significant flora or vegetation listed under the *Wildlife Conservation Act 1950* (WC Act) or the EPBC Act.
- Heritage – no special cultural or historical significance has been identified through a completed heritage study and consultation with stakeholders familiar with the area.

- No flooding – the development envelope is not subject to flooding, nor is it predicted to be in the future. The site is at very low risk of encountering cyclones.
- Very low rates of erosion – the development envelope has extremely low rates of erosion and there is no possibility of glacial activity in the future.

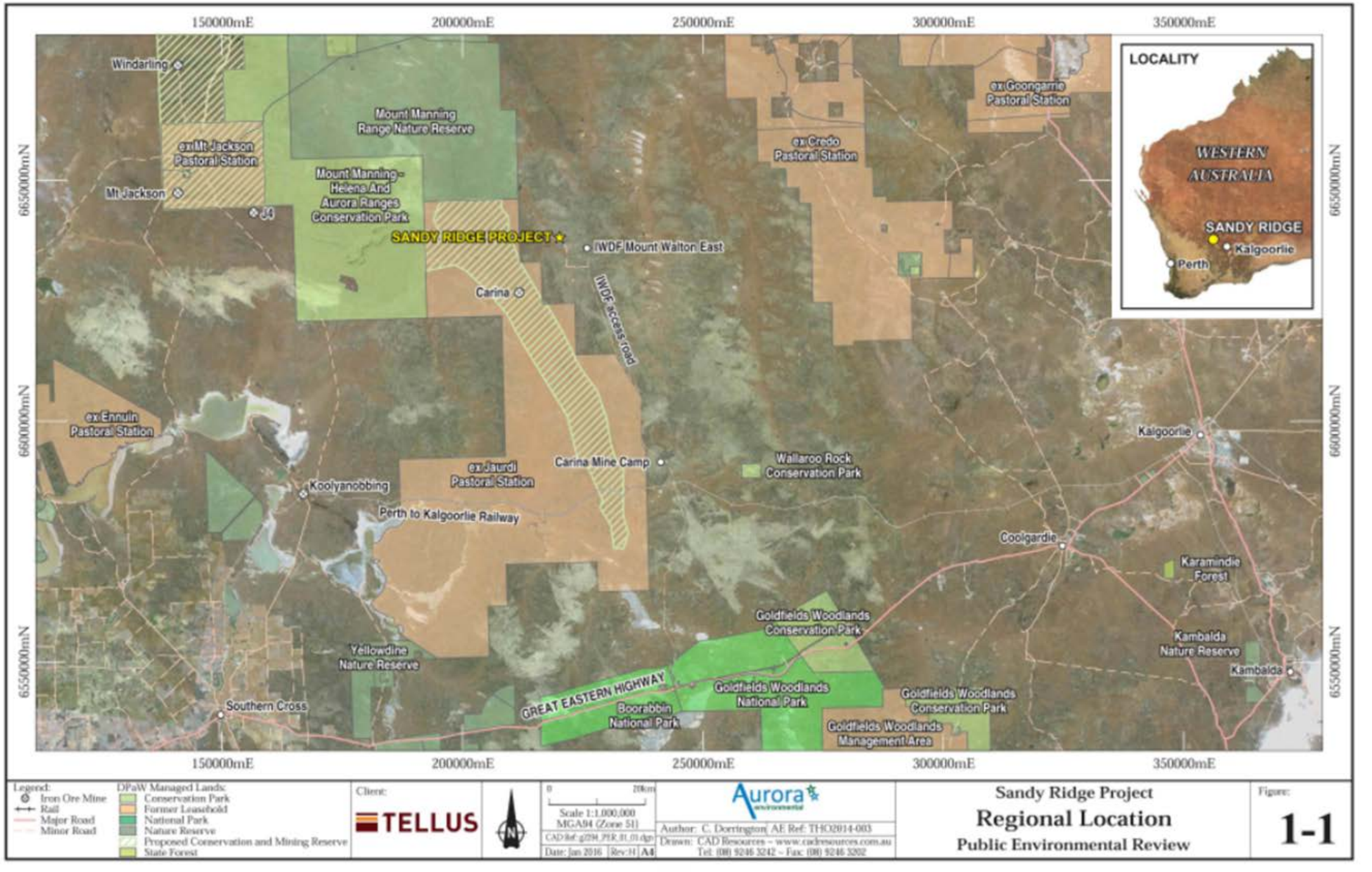


Figure 1: Location Map

3 RADIOACTIVE WASTE CLASSIFICATION

Radioactive waste is defined as ‘radioactive material in gaseous, liquid or solid form for which no further use is foreseen, and which is controlled as radioactive waste by a regulatory body’.

In Australia there are 2 main documents in relation to the classification of radioactive waste:

- The ARPANSA Safety Guide for Classification of Radioactive Waste (2010).
- NHMRC Code of practice for the near surface disposal of radioactive waste in Australia (1992) (RHS35) - currently under review.

In Australia, a system of categorising radioactive waste relating to near surface disposal is proposed in the NHMRC Code of practice for the near surface disposal of radioactive waste in Australia (1992) (RHS35). The classification was based on international recommendations for radioactive waste management adapted for the type of waste generated in Australia. Those categories suitable for near surface disposal are Category A, Category B and Category C. Category S is not suitable for near surface disposal. The classification is only used by regulatory authorities to classify waste destined for disposal, not as a general classification system.

The classification of radioactive waste has also been defined in the General Safety Guide Classification of Radioactive Waste (No. GSG-1) published by the IAEA in late 2009.

Under the current international guidance, there is not a precise boundary between each of the waste categories, as limits on the acceptable level of activity concentration will differ between individual radionuclides or groups of radionuclides.

The ARPANSA Safety Guide for Classification of Radioactive Waste (2010) largely reflects the international guidance referred to above. As such, it does not include quantitative values of allowable activity content for each significant radionuclide. Radioactive waste generated in Australia generally falls within the VSLW, VLLW, LLW or ILW classifications. Australia does not generate any electricity from nuclear power and therefore currently does not generate any used fuel that would be classified as HLW.

- Exempt waste – is excluded from regulatory control because radiological hazards are negligible.
- Low-level waste (LLW) - may include short lived radionuclides at higher levels of activity concentration and also long-lived radionuclides, but only at relatively low levels of activity concentration. LLW covers a very wide range of radioactive waste, from waste that does not require any shielding for handling or transportation, up to activity levels that require more robust containment and isolation periods of up to a few hundred years

- Intermediate-level waste (ILW) - contains increased quantities of long-lived radionuclides and needs an increase in the containment and isolation barriers compared to LLW. ILW needs no provision for heat dissipation during storage and disposal. Long-lived radionuclides such as alpha emitters will not decay to a level of activity during the time for which institutional controls can be relied upon.
- High-level waste (HLW) - is sufficiently radioactive to require both shielding and cooling, generates >2 kW/m³ of heat and has a high level of long-lived alpha-emitting isotopes.

The Disposal facility will only accept Low Level Waste (LLW). i.e., Low level waste and short lived intermediate level waste as per ARPANSA 2010 Correspond to Category A, B or C under the NHMRC 1992.

3.1 WASTE TYPES

The types and form of radioactive waste that are likely to be managed at the Facility would be generated from:

- Medical research and industry (use of radioisotopes and sealed radioactive sources which contains low activity concentrations).
- Industrial gauges and commercial sources.
- Mining and processing of mineral ores or other material containing naturally occurring radioactive material (NORM), such as phosphate minerals, mineral sands, coal, some gold bearing rocks and hydrocarbons. These generally contain long lived radionuclides at relatively low concentrations. NORM such as scales arising in the oil and gas industry may have higher activity concentration levels but would still be categorised as low level wastes. NORM wastes may include contaminated equipment and piping.
- Intervention actions, which are necessary after accidents or to remediate areas affected by past practices.
- Disposal of disused sealed radioactive sources (including orphan sources).

All wastes need to be ‘characterised’. This means that information is collected about the waste in order to build up a picture of its properties. Data is collected about the radiological, chemical and physical properties of the waste. This information helps to decide how the waste should be handled, packaged, stored and safely disposed of by the facility.

4 RADIOACTIVE WASTE MANAGEMENT

The effective management of low and intermediate level waste depends on knowledge of the waste characteristics and the contained radioactivity.

The property of radioactive waste varies, not only in terms of radioactive content and activity concentration but also in terms of physical and chemical properties. A common characteristic of all radioactive waste is its potential to present a hazard to people and to the environment, and it must, therefore, be managed so as to reduce any associated risk to acceptable levels.

The preferred strategy for the management of all radioactive waste is to contain it (i.e. to confine the radionuclides to within the waste matrix, the packaging and the disposal facility) and to isolate it from the environment.

This section provides a broad overview of the waste, predisposal practices and the proposed waste acceptance criteria. More detailed description of the management strategies that will be implemented is given in the Radiation Waste Management Plan (RWMP) and in the Waste Storage and Disposal Zoning Procedure (TCO-5-05-004).

4.1 PREDISPOSAL MANAGEMENT OF RADIOACTIVE WASTE

The overall objective of predisposal management of radioactive waste is to produce waste packages that can be handled, transported, stored and disposed securely and safely. In addition to compliance with individual dose limits, the practices that are adopted in waste conditioning, packaging and other containment shall be carried out to ensure that any potential exposure will be as low as reasonable achievable.

Below is a brief description as to how Tellus proposes to manage radioactive waste accepted at the Proposal. More detail on exposure control and waste management practices is given in the RWMP.

4.1.1 SEALED SOURCES

Sealed sources will upon receipt be stored in the Radioactive Waste Warehouse, unpacked, inspected and verified. After verification, sources will be secured in a 60 L drum inside a 200 L drum. As illustrated in Figure 2, high density cement grout will be added to the 60 L drum to fill all the void spaces and to cover all the items. The cement filled 60 L drums will be placed in the centre of a 200 L drum, which is then filled with high density cement grout. The 200 L drum will be marked with its identification number and labelled. These drums will be stored until the shaft is prepared for disposal. Drums will then be transferred to the cell, loaded into the shaft and covered and surrounded with kaolinised granite fill or other non-reactive wastes combined with pozzolanic material to form a cementitious mixture.

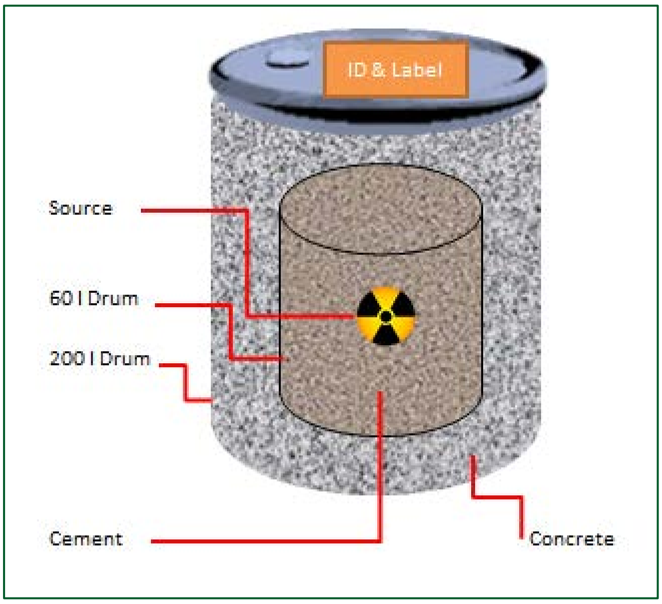


Figure 2: Packaging of sealed sources

4.1.2 NORM CONTAINING PASTES / SLUDGES / LIQUIDS

Once delivered to site NORM containing pastes, sludges or liquids, will be stored in the Radioactive Waste Warehouse or in sea containers on hardstand (dependent upon activity). In campaigns waste will be unpacked, inspected and verified by laboratory testing. If required the waste will then be treated with absorbent and pozzolanic materials to form a slurry which will solidify and stabilise the waste. The slurry can be placed into drums, moulds, or contained sections of the cell where it will set to form a stable solid.

4.1.3 CONTAMINATED SOLID MATERIALS

Contaminated solid material will be stored in Radiation Store building or in sea containers on hardstand (dependent upon activity) until suitable space is available in cell. Depending upon physical size and shape of materials, type and activity of radiation, these wastes can either be:

- Compacted in drums and filled with kaolin or cement grout prior to disposal.
- Crushed or cut to remove void space and fill remaining voids in with cement grout or kaolinised granite solids.
- If necessary, an entire sea-container or whole equipment into a cell, and all void spaces filled with cementitious grout material.

4.1.4 CONTAMINATED SOIL OR SANDS (BULK MATERIAL)

Bulk contaminated soils or sands will be delivered to site in either bulk bags, shipping containers or as wetted down sand, depending on volume and physical characteristics of material. Practical transport will be arranged to coincide with a disposal campaign so it can be disposed of directly into pit, but if not viable, the material will be stored in the Radioactive Waste Warehouse. For large volumes of material, separate stockpile areas will be set up (adhoc stockpiles), and dust control measures introduced. These are discussed in section 9.2 of the radiation management plan and include a designated stockpile area with concrete slab and bunded walls, closing stockpile with tarpaulin material, dust suppression agents and a monitoring program to confirm efficiency of controls implemented. The stockpile area and surrounding area will be screened after removal of the stockpile to ensure dose rate levels are back to background radiation levels. The bulk material can be disposed of directly in the cell, diluted or mixed with other material, or mixed with binders or pozzolanic materials if required.

5 DISPOSAL OF RADIOACTIVE WASTE

Disposal options are designed to contain the waste by means of passive engineered and natural features and to isolate it from the environment to the extent necessitated by the associated hazard. The term ‘disposal’ refers to the emplacement of radioactive waste into a facility or a location with no intention of retrieving the waste. The term disposal implies that retrieval is not intended; it does not mean that retrieval in not possible.

The specific aims of disposal are:

- To contain the waste.
- To isolate the waste from the environment and to reduce substantially the likelihood of, and all possible consequences of, inadvertent human intrusion into the waste.
- To inhibit, reduce and delay the migration of radionuclides at any time from the waste to the environment.
- To ensure that the amount of radionuclides reaching the environment due to any migration from the disposal facility are such that possible radiological consequences are acceptably low at all times.

5.1 NEAR SURFACE DISPOSAL

Near-surface disposal of low level waste (LLW), at varying depths down to about 30 metres below ground surface, has been practiced internationally for over 20 years. Near surface repositories provide adequate containment for short lived low and intermediate level waste and for some long lived low and intermediate level waste when greater confinement is provided.

The rationale of near surface disposal depends on the assumption that, by the end of the institutional control period, the activity of the waste will have decayed to harmless levels with respect to likely future uses of the site and consequent potential exposure pathways. For a geological repository, the site provides significantly longer isolation of the waste (for geological time).

5.2 FACILITY DESIGN

During the feasibility stage of the project consideration were given to engineering best practice as well as socio economic considerations to determine the most suitable design that will meet the safety requirements at acceptable cost. The current proposal is open cut pit with in-cell vertical shaft disposal of sealed source radioactive wastes. During the waste disposal process a roof canopy is positioned over the cell to exclude rainwater prior to the capping layer being installed. There may be instances (for non-soluble waste types) where a cell may be filled with waste without a roof canopy. In addition, any potential stormwater surface flows would be diverted away from the cells by bund walls or levee banks.

A hybrid solution identified for the storage of sealed source radioactive wastes which cannot be placed in an open-cell with other chemical wastes is the construction of shafts within the planned open-cell storage. A number of shafts can be constructed within a cell using pre-formed cylindrical shaft segments. As the cell is progressively filled with other wastes, more segments are stacked upon each other to create a shaft. A buffer of compacted kaolinised granite is placed around each segment and bulk NORM wastes are also used to provide further isolation from chemical waste.

Sealed source waste can be placed into the shaft at any time, but it is expected that the shaft will progress to several metres of depth before a campaign of waste placement takes place, so as to provide a level of physical separation and a shield between the radioactive waste and workers on the active surface. Waste drums are lowered into the shaft and each layer is backfilled with kaolinised granite to fill void spaces. Higher activity wastes can be backfilled with cementitious slurry if required. A concrete lid is used on the shaft to prevent un-authorised human entry. Upon the shaft reaching and being filled with waste to the base of cap level, the lid is left in place and the structure is covered by the cell cap materials The cost per unit of waste placement in this manner is less than underground mining and blind shaft sinking methods considered, but is far less risky than either of the alternatives as it is not dependent upon ground conditions and shafts can be constructed on-demand. This method is also able to be constructed with no special skills.

The geological environments allow the post-closure safety requirements to be achieved without relying on the integrity of the waste packages. In these cases, the prime function of the containers is to provide operational and transport safety.

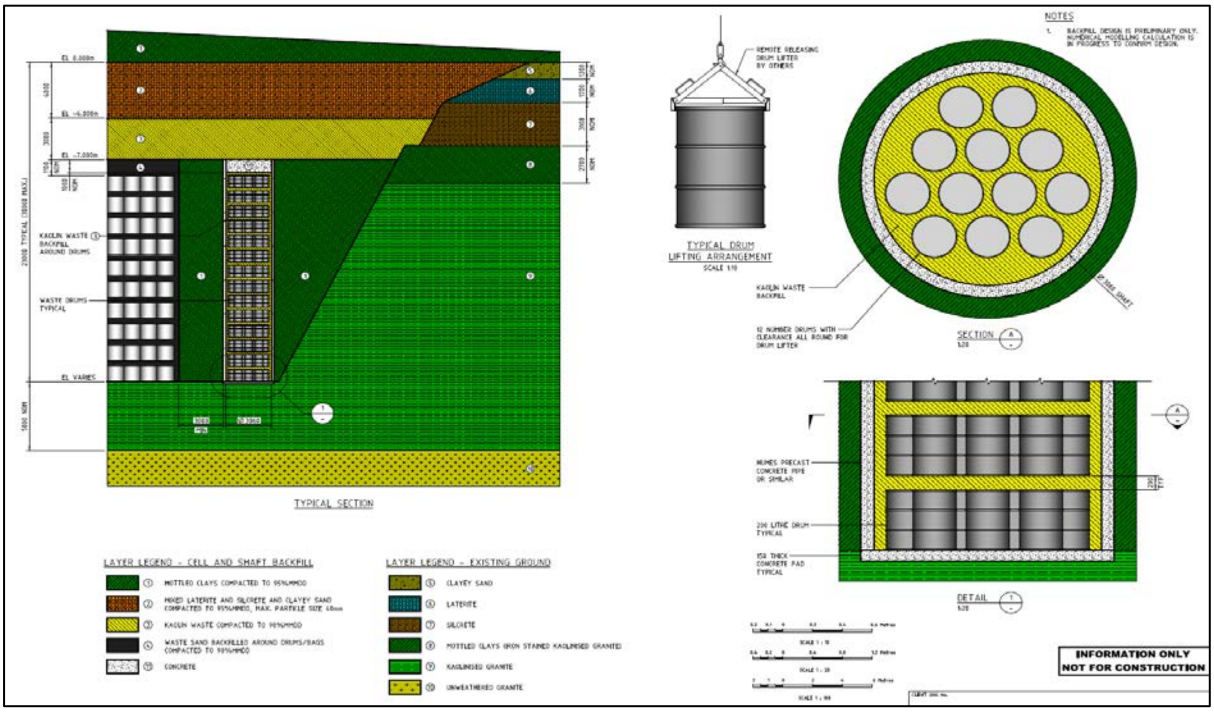


Figure 3: Shaft design

NORM wastes are placed in the open cell for disposal, in accordance with the Waste Storage and Disposal Zoning Procedure. Slurry or liquid form wastes will be mixed with kaolinised granite as an absorbent and pozzolanic materials prior to placement to create a cementitious mixture with at least 0.35MPa strength. A cover layer of compacted kaolinised granite or other un-reactive bulk waste is placed over layers of NORM waste if that layer is to be a working surface for people or machines in the placement of other wastes in subsequent layers.

5.3 CAPPING DESIGN

Once all wastes are placed in the cell and the area is ready for closure, an engineered cap consisting of compacted backfill materials is placed into the remaining void. This cap serves several purposes; preventing surface or meteoric water from entering the waste storage area and mobilising soluble waste chemicals, preventing erosion, acting as a barrier to un-authorised access of the isolated waste materials, and providing a barrier to radioactive emissions.

The engineered cap reduces the level of external exposure by covering the waste with a layer of “clean” material. This material absorbs gamma radiation emitted by the radionuclides in the waste, and also inhibits the exhalation of radon. The presence of the cover also removes the possibility of internal exposure via the dust inhalation pathway and of external exposure from material which settles on the skin.

The construction of the cap is completed by an earthmoving contractor whilst new waste placement activities occur in the next cell. After a monitoring period of 10 years, further overburden and soils are placed over the cap and progressive rehabilitation commences.

The long term (10,000 plus years) performance of the cap has been modelled using both near-surface hydrogeological and erosion modelling software. The modelling has confirmed that the cap design is robust from both water infiltration and erosion aspects.

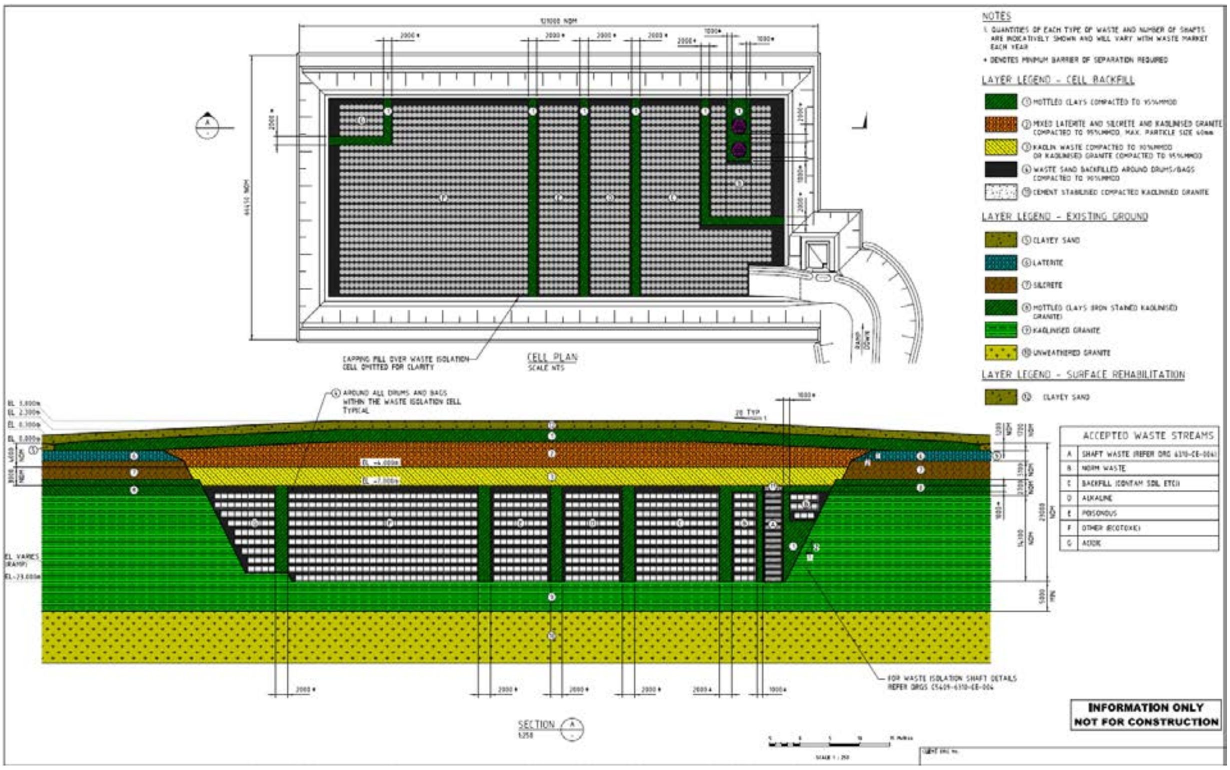


Figure 4: Cell backfill and cap design (section view)

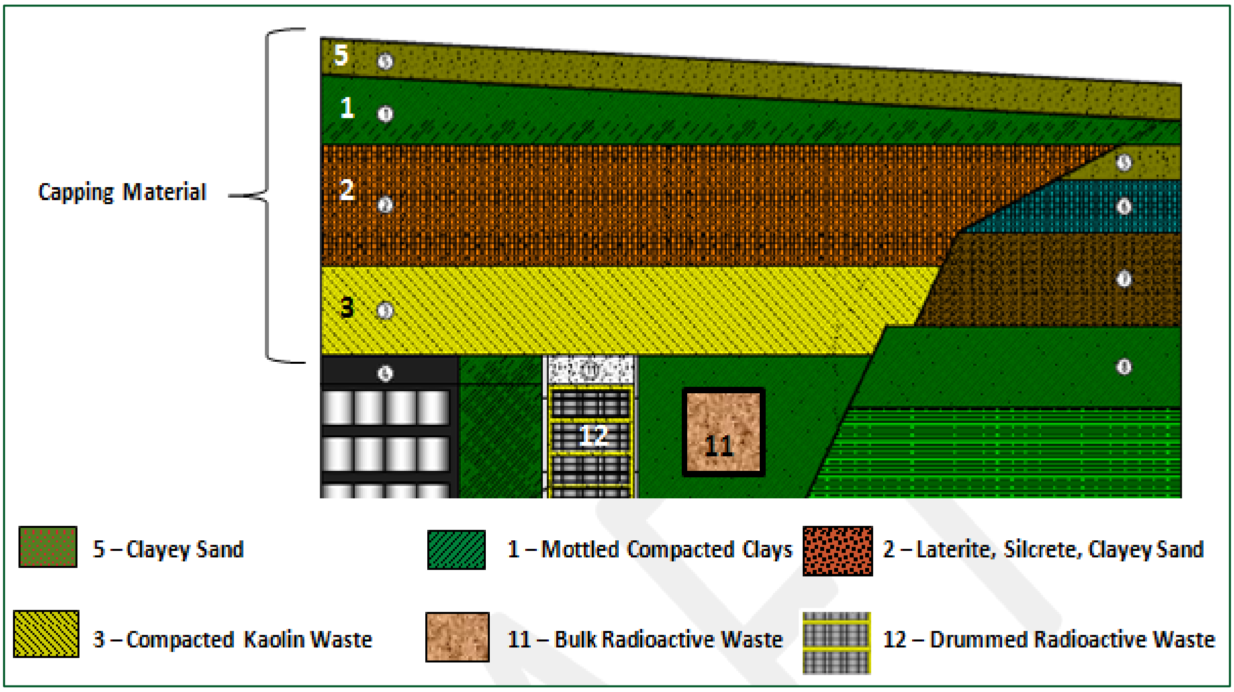


Figure 5: Post Closure and Rehabilitation of the Facility

5.4 MONITORING

Rehabilitation is progressive during the life of the facility. Monitoring of the clay caps over each cell takes place for 10 years before the final placement of surplus overburden, sub-soil and topsoil over the cap.

5.5 CLOSURE & REHABILITATION

After a period of monitoring to confirm the stability and integrity of the clay cap capping, topsoil will be placed over the cap and the area re-vegetated with species of local provenance. The root zone of these local flora species is such that the engineered cap would not be compromised and that direct uptake of radionuclides in not possible.

Tellus propose that a post-closure management plan over an agreed period of time is provided to ensure the integrity of the disposal cell caps and demonstrate that all waste is securely contained before responsibility for the site is transferred to the State Government.

5.6 FUTURE LAND USE

Any radiological assessment of the possible consequences of near surface disposal has to take into account the future use of the disposal site after the waste disposal phase has ended.

Upon demonstrating that all waste is securely contained and the site is suitable for commencement of the ICP, the responsibility for the site will be transferred to the State Government.

5.7 RADIOLOGICAL PROTECTION IN THE LONG TERM

The primary design goal of a radioactive waste disposal facility is to provide for the protection of human health and the environment in the long term, after the facility is closed and until the time when the associated radiological hazard will reach an insignificant level. In this period, the migration of radionuclides to the environment and consequent exposure of humans may occur due to slow degradation of barriers, slow natural processes and also following discreet events that may alter the disposal system barriers or lead to short term release of radionuclides [30]. Radiological protection criteria relevant to the post-closure phase of near surface disposal facilities are set out in the relevant IAEA Requirements [18] and in recent ICRP publications [29].

Radioactive waste disposal facilities shall be sited, designed, constructed, operated and closed so that protection in the long term is optimised, social and economic factors being taken into account, and a reasonable assurance provided that doses or risk in the long term will not exceed the dose or risk constraint for members of the public [30].

The dose limit for members of the public during operations from all sources is an effective dose of 1 mSv in a year, and this or its risk equivalent should be considered as criteria not to be exceeded. To comply with this limit, Tellus is designing the facility so that the estimated average dose or risk to members of the public, who may be exposed as a result of the disposal facility in the future, shall not exceed a dose constraint of 0.3 mSv in year.

The ICRP has given guidance on radiological criteria applied to human intrusion [29]. In circumstances where human intrusion could lead to doses to those living around the site sufficiently high that intervention on current criteria would almost always be justified, reasonable efforts should be made to reduce to probability of human intrusion or to limit its consequences. In this respect the ICRP has advised that an existing annual dose of around 10 mSv may be used as a generic reference level below which intervention is not likely to be justifiable and that an existing annual dose of around 100 mSv may be used as a generic reference level above which intervention should be considered always justifiable.

6 SAFETY ASSESSMENT

To determine whether a specific waste disposal practice will have unacceptable radiological effects, either direct or indirect, on humans, a ‘safety assessment’ must be carried out. The assessment aim to analysis of the system in order to predict its behaviour, comparison of the results with appropriate standards or criteria expressed the radiological impact in terms of dose or risk.

Safety assessments can also be utilised to assess and compare the feasibility of a range of disposal options in a generic manner and to develop quantitative and qualitative waste acceptance criteria. They can also be used to show which environmental exposure pathway are the most important for specific waste types, disposal facilities design and generic disposal sites.

An important part of the safety assessment for a near surface repository is estimation of the dose from inadvertent intrusion scenarios that hypothetically occur after the institutional control period. This dose is dependent on the specific activity of the waste in the repository at the time of intrusion and the engineering controls I place to safeguard humans.

There are many ways in which a disposal site could potentially present a radiation hazard and therefore a number of exposure scenarios can be postulated. Release of radionuclides into groundwater and their subsequent migration, together with human intrusion, intentional and unintentional, are two important means by which material buried in near surface sites can present a radiological hazard. Other scenarios relating to natural processes such as wind and water erosion may also need to be considered.

RESRAD is a computer model designed to estimate radiation doses and risks from residual radioactive materials. The model estimates direct exposure to external radiation from contaminated soil and internal dose from the inhalation of airborne radionuclides originating from contaminated soil or from radon emissions thereof.

The model also calculates internal doses from the ingestion of contaminated vegetables and leafy greens, meat, fish, milk, drinking water, and soil. The RESRAD code has become popular because of its adaptability to specific exposure situations, and its models being verified and validated as benchmarked against other codes in the environmental assessment and site clean-up arena (Faillance et al. 1994) [2].

The RESRAD (onsite) computer code evaluates the radiological dose and excess cancer risk to an individual who is exposed while residing in an area where the soil is contaminated with radionuclides Figure 6 illustrates all the potential exposure pathways that can be included in the RESRAD modelling. (Yu et al. 2001). Not all of these pathways (as per Figure 6) are relevant to the Sandy Ridge site. Where a pathway is not relevant it was excluded from the assessment.

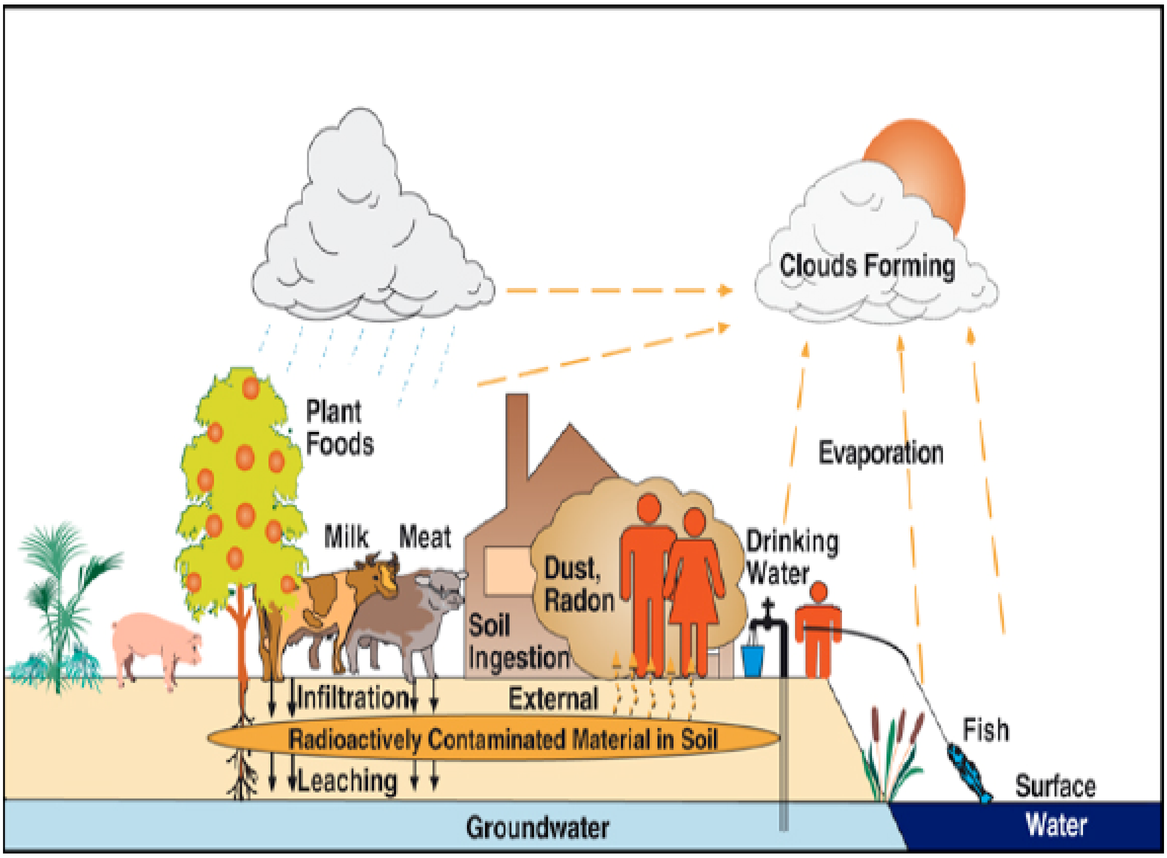


Figure 6: Potential pathways of exposure (RESRAD onsite)

7 EXPOSURE ASSESSMENT RATIONAL

It is necessary to consider the consequences of disturbance of the waste by human activities (human intrusion) at the end of the institutional control period. The likelihood of such an intrusion was reduced by choosing a site with low resource potential, low population, no agricultural or environmental value, engineered control and containments and ensuring that suitable government controls are established to manage future land uses at the site and records of what is contained within the site.

The RESRAD modelling tool (as well as first principle calculations) was used to assess the proposed waste disposal system in order to predict its behaviour, followed by comparison of the results with appropriate standards or criteria.

Four post-closure exposure scenarios were identified and are discussed below. The RESRAD tool was also used to determine the waste acceptance criteria for NORM waste and is also discussed in the report as scenario 5.

7.1 SCENARIO 1: HUMAN INTRUSION NEXT TO THE SHAFT CONTAINING CATEGORY B SEALED RADIOACTIVE SOURCES

For Scenario 1, a hypothetical scenario was assumed where a person excavates or digs next to the disposal shaft that contains sealed radioactive sources as illustrated in Figure 7.

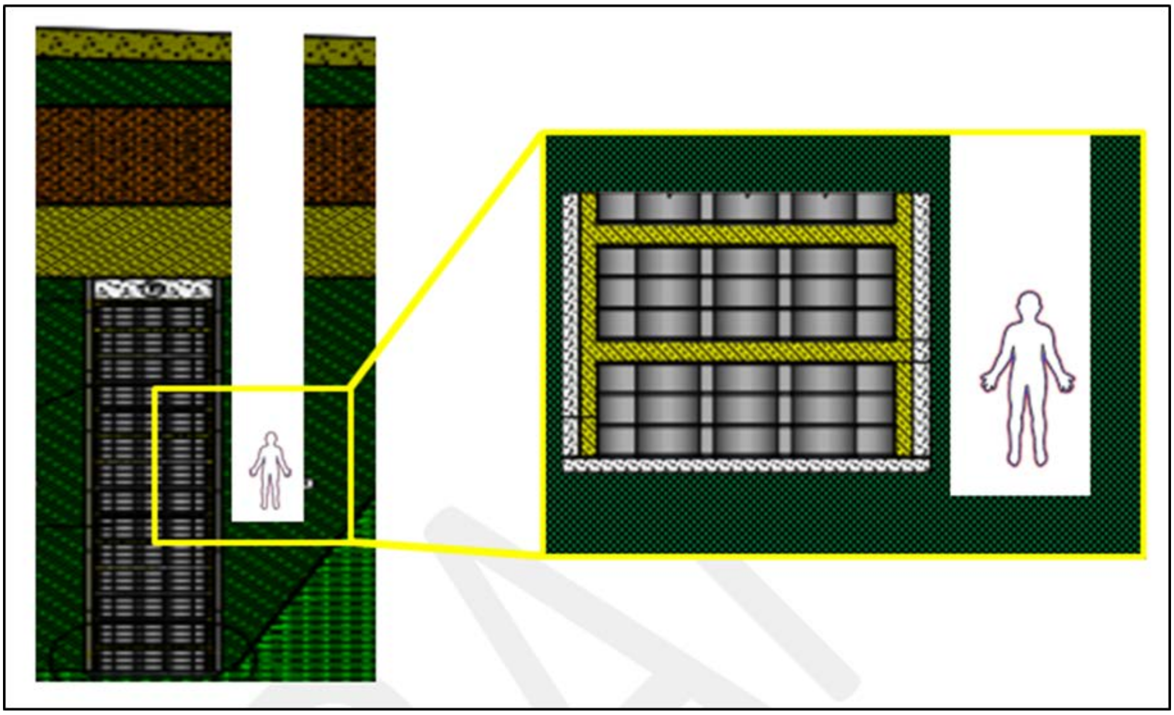


Figure 7: Scenario 1- Human intrusion next to radioactive sources shaft

The dose that will be received by a member of the public is dependent on the activity concentration of sources at the time exposure, the duration of exposure, distance from the shaft and shielding. Shielding will be provided by the double-isolated and concrete entombed packaging of sources (as discussed in section 4.1) and the shaft itself containing further shielding of either kaolinite material or concrete. High activity sources can also be packaged (and is likely to be so for transport) in lead casings. These will provide further shielding.

For the assessment it was assumed that the scenario occurs 100 years after disposal, that the maximum activity level (as per WAC) sources were disposed of and that the individual is directly next to the concrete shaft.

In the assessment the following shielding were assumed and is illustrated in Figure 8:

- 0.285 m concrete in drums
- 0.0013m steel around drums
- 0.2 m concrete from shaft.
- Lead casing of 0.0255m around high activity Cs137 sources.

- Shielding that will be provided from either waste kaolinite material or additional concrete inside the shaft was excluded from the assessment.

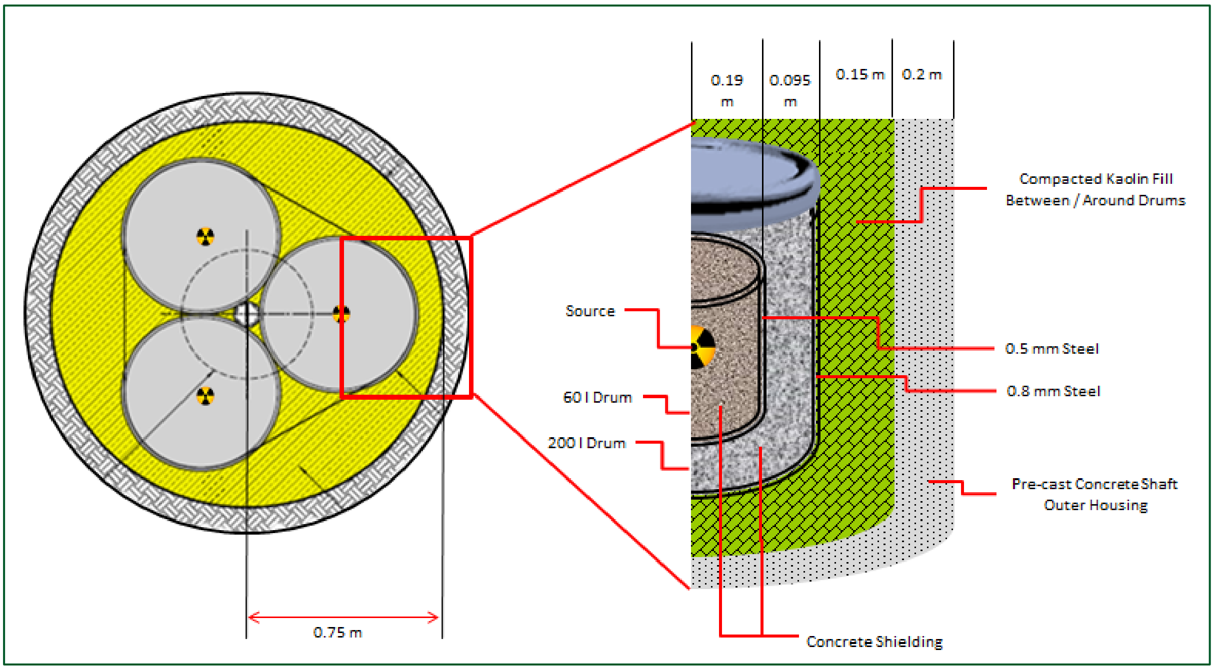


Figure 8: Source shielding prior to placement in shaft

Table 1 lists man-made radioisotopes (used in sealed sources) and assumed activity concentrations identified as the higher risk isotopes requiring shielding and control. The selection was based on half-life (preference to isotopes with half-lives 30 years and above); danger category (categories 2 & 3); and gamma energy, e.g. even though Pu-238 is a long lived nuclide with a half-life of 88 years, it is an alpha emitter with very little photon energy, therefore requiring almost no shielding, and was therefore not considered as higher risk due to its mode of decay. The activity concentration assumed is the upper limit for Category B waste as defined in NHMRC (1992)]. If “no limit” was given the activity assumed is the maximum activity disposed of at similar facilities.

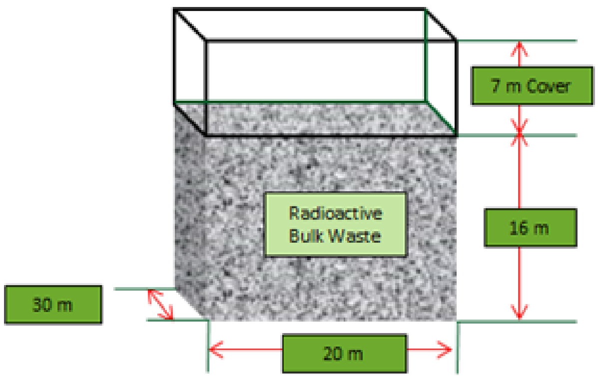
Table 1: Man-made isotopes and concentrations used in assessment.

Radioisotope	Symbol	Half-life	Initial Concentration Assumed (Bq)*
Americium-241	Am-241	432.17 y	2.00E+10
Caesium-137	Cs-137	30.07 years	2.00E+11
Californium-252	Cf-252	2.6 years	2.00E+10
Cobalt-60	Co-60	5.27 years	5.40E+07
Iridium-192	Ir-192	73.8 days	2.00E+10
Radium-226	Ra-226	1,600 years	1.00E+09
Selenium-75	Se-75	120 days	3.70E+08
Thulium-170	Tm-170	129 days	7.40E+12
Ytterbium-169	Yb-169	32 days	3.70E+11

7.2 SCENARIO 2 AND 3: HUMAN INTRUSION- LIVING ON EXPOSED BULK WASTE AT ACTIVITY CONCENTRATION LEVELS OF CATEGORY A AND C

Scenario 2 and 3 is representative of a case where the cell cap is completely removed and humans are living (unaware) on top of the bulk waste, this is also a surrogate for an archaeological dig taking place. The RESRAD modelling software to evaluate “human intrusion” into bulk radioactive waste at activity concentration levels of Category A (Scenario 2) and Category C (Scenario 3) wastes as per NHMRC (1992).

The assumed area and depth of waste assumed is shown in Figure 9.



Waste Surface Area:	600	m^2
Waste Depth:	16	m^2
Waste Volume:	9600	m^3
Waste Density:	1.5	t/m^3
Waste Tonnage:	14400	t
Radius of circle with equivalent surface area	13.82	m

Figure 9: Assumed area and depth of bulk NORM waste within the cell

To enable worst case modelling and comparison to the ICRP guidance on radiological criteria applied to human intrusion [29] occupancy of 50% (4,380 h/y) indoors and 25% (2,190 h/y) outdoors {as per default RESRAD occupancy for a resident scenario} was assumed. The event was modelled to occur at the end of the ICP (maximum dose). RESRAD input values used is given in Table 2.

Table 2: RESRAD input values for Scenario 2 and 3

Input Parameter	Scenario 2	Scenario 3
Description	Human Intrusion into Category A Waste	Human Intrusion into Category C Waste
Pathways	External Dust Radon Soil Ingestion	External Dust Radon Soil Ingestion
Capping thickness	0	0
Thickness of unsaturated zone	5 m	5 m
Erosion rate	0.00005 m/y (waste erosion)	0.00005 m/y (waste erosion)
Cover porosity	N/A	N/A
Cover radon diffusion coefficient	N/A	N/A
Contaminated fraction of household water	0	0
Groundwater fractional usage – household	0	0
Wind speed	5 m/s	5 m/s
Rainfall / precipitation	0.3 m/y	0.3 m/y
Occupancy	50% Indoors 25% Outdoors	50% Indoors 25% Outdoors
Density of contaminated zone	Site specific 1.5 t/m^3	Site specific 1.5 t/m^3

Input Parameter	Scenario 2	Scenario 3
Density unsaturated zone	Site specific 1.6 t/m^3	Site specific 1.6 t/m^3
Cover density	N/A	N/A
Area of contamination	600 m^2	600 m^2
Depth of contamination	16 m^{π}	16 m
Length parallel to aquifer flow	13.82 m	13.82 m
Catchment Area	100 km^2 ($1x10^{10}$ m^2)	100 km^2 ($1x10^{10}$ m^2)

Occupancy hours that will result in 100mSv/year and 10mSv/year (are per ICRP guidance on radiological criteria applied to human intrusion [29]) were determined to demonstrate the dependence of dose on exposure time and that with the multiple levels of controls in place the risk is manageable. In reality, the human intrusion scenario (where cap has been removed/eroded and waste is on surface as per Scenario 2 and 3) at Sandy Ridge is considered to be highly unlikely and the risk is mitigated through engineering controls, site selection, cap design including a cover of 7 m minimum upon closure.

7.3 SCENARIO 4: RECREATIONAL VISITOR TO THE SITE POST CLOSURE

Scenario 4 used the RESRAD modelling software to evaluate exposure of a recreational visitor to the facility (post closure with a minimum of 7 meters capping material) where bulk radioactive waste at activity concentration levels of Category C were disposed of. It was assumed that exposure will occur for 3.5 days per year.

Table 3: RESRAD input values for Scenario 4

Input Parameter	Scenario 4
Description	Recreational Visitor
Pathways	External Dust Radon
Capping thickness	7 m
Thickness of unsaturated zone	5 m
Erosion rate	0.00005 m/y
Cover porosity	0.1
Cover radon diffusion coefficient	0.000001 m^2/s
Contaminated fraction of household water	0

Input Parameter	Scenario 4
Groundwater fractional usage – household	0
Wind speed	5 m/s
Rainfall / precipitation	0.3 m/y
Occupancy	3.5 days/year
Density of contaminated zone	Site specific 1.5 t/m^3
Density unsaturated zone	Site specific 1.6 t/m^3
Cover density	Site specific 1.86 t/m^3
Area of contamination	600 m^2
Depth of contamination	16 m[π]
Length parallel to aquifer flow	13.82 m
Catchment Area	100 km^2 (1x10^{10} m^2)

General assumptions for modelling:

- For most scenarios a basic radiation dose constraint of 0.3 mSv/y was adopted in line with best practice and the Radiological Council of WA Industry Guideline ‘Reporting of Radiologically Contaminated Site NORM (2009)’. The RESRAD default is 0.25 mSv/y;
- 1.86 t/m3 cover density as calculated from the weighted average of different layers of cover material (3 m of compacted kaolin at 1.7 t/m^3 + 4 m of compacted laterite, silcrete, clayey sand mix at 2.1 t/m^3 + 0.8 m of compacted clay at 1.9 t/m^3 + 1.2 m of clayey sand at 1.4 t/m^3)

7.4 SCENARIO 5: WASTE ACCEPTANCE CRITERIA - CONCENTRATIONS LIMITS FOR NORM

In order to derive activity concentrations limits for individual radionuclides in NORM bulk wastes, two criteria were followed:

- Dose rate to a human receptor post closure (with capping material in place) to not exceed a dose constraint of 0.3 mSv in a year. Occupancy of 3.5 days a year was assumed as per ARPANSA TRS No. 141 [15] for an arid and remote site.
- Dose rate to a human receptor upon intrusion (no capping) corresponding to 10mSv/y.as per ICRP guidance on radiological criteria applied to human intrusion [29].

The RESRAD (Onsite) code was used, with conditions as specified in Table 4, to determine radionuclide activity concentration levels in bulk NORM wastes which would give rise to conditions as specified above for post closure and intrusion scenarios. Table 4 also includes dose rates which would result from exposure to waste containing individual nuclide concentrations as per Category C of the Near Surface Code [17] (NHMRC), both for post closure and intrusion. Modelling on Category C waste was conducted on a hypothetical scenario as per ARPANSA TRS No. 141 [15] for an arid and remote site as well as for Sandy Ridge specific conditions to determine if dose rates would adhere to conditions specified above.

These activity concentrations are intended to be used in the development of the radionuclide limits for NORM waste to be included in the site WAC.

Table 4: Scenario 5 specific RESRAD input values for determination of individual NORM Radionuclide limits for WAC

Input Parameter	Category C of the Near Surface Code [17] (NHMRC)				Determination of Individual Radionuclide Activity Concentration of Bulk NORM Waste		
Description	Conceptual Model for an Arid and Remote site (TRS No 141 [15]) on Category C waste, nuclides with $T_{1/2} \geq 30$ y.		Site Specific Conditions on Category C waste, nuclides with $T_{1/2} \geq 30$ y.		Waste giving rise to 10 mSv/y upon Intrusion	Waste giving rise to 50 mSv/y upon Intrusion	Waste giving rise to 100 mSv/y upon Intrusion
	Post Closure	Human intrusion	Post Closure	Human intrusion	Human intrusion	Human intrusion	Human intrusion
Institutional Control Period	100 years	100 years	100 years	100 years	100 years	100 years	100 years
Individual Radionuclide Concentrations (Bq/g)*					To be determined by RESRAD modelling		
Uranium-238	10000 (Bq/g)						
Uranium-234	10000 (Bq/g)						
Thorium-230	10000 (Bq/g)						
Uranium-235	10000 (Bq/g)						
Protractinium-231	10000 (Bq/g)						
Radium-226	500 (Bq/g)						
Thorium-232	500 (Bq/g)						
Pathways	External Dust Radon Ingestion: Plant Water Meat Milk	External Dust Radon Ingestion: Plant Water Meat Milk	External Dust Radon	External Dust Radon Soil Ingestion	External Dust Radon Soil Ingestion	External Dust Radon Soil Ingestion	External Dust Radon Soil Ingestion
Capping thickness	5 m#	0	7 m@	0	0	0	0
Thickness of unsaturated zone	5 m#	5 m#	N/A	N/A	N/A	N/A	N/A

Input Parameter	Category C of the Near Surface Code [17] (NHMRC)				Determination of Individual Radionuclide Activity Concentration of Bulk NORM Waste		
Erosion rate	0.0003 m/y#	0.0003 m/y# (waste)	0.00005 m/y@ (Sandy Ridge)	N/A	N/A	N/A	N/A
Cover porosity	default	N/A	0.1^	N/A	N/A	N/A	N/A
Cover radon diffusion coefficient	default	N/A	0.000001 m^2/s^	N/A	N/A	N/A	N/A
Contaminated fraction of household water			0[a]	0[a]	0[a]	0[a]	0[a]
Contaminated fractions for all pathways of ingestion	0.01#	0.01#					
Groundwater fractional usage – household			0[a]	0[a]	0[a]	0[a]	0[a %]
Groundwater fractional usage (all)	0.01#	0.01#					
Wind speed	default	default	5 m/s@	5 m/s@	5 m/s@	5 m/s@	5 m/s@
Rainfall / precipitation	0.3 m/y#	0.3 m/y#	0.3 m/y@	0.3 m/y@	0.3 m/y@	0.3 m/y@	0.3 m/y@
Occupancy	3.5 days/year# (0.0096 Fraction)	1 day/year (0.0027 Fraction)	3.5 days/year[5] (0.0096)	1 day/year (0.0027)	1 day/year (0.0027)	1 day/year (0.0027)	1 day/year (0.0027)
Density of contaminated zone	1.5# t/m^3	1.5# t/m^3	Site specific@ 1.5 t/m^3	Site specific@ 1.5 t/m^3	Site specific@ 1.5 t/m^3	Site specific@ 1.5 t/m^3	Site specific@ 1.5 t/m^3
Density unsaturated zone	Default 1.5 t/m^3	Default 1.5 t/m^3	Site specific@ 1.6 t/m^3	Site specific@ 1.6 t/m^3	Site specific@ 1.6 t/m^3	Site specific@ 1.6 t/m^3	Site specific@ 1.6 t/m^3
Cover density	Default 1.5 t/m^3	N/A	Site specific@ 1.86 - t/m^3	N/A	N/A	N/A	N/A
Waste Tonnage	3 Million Tonnes#	3 Million Tonnes#	14400@ Tonnes	14400@ Tonnes	14400@ Tonnes	14400@ Tonnes	14400@ Tonnes
Area of contamination	1000000# m^2	1000000# m^2	600@ m^2	600@ m^2	600@ m^2	600@ m^2	600@ m^2
Depth of contamination	2 m#	2 m#	16@ m[π]	16@ m[π]	16@ m[π]	16@ m[π]	16@ m[π]

Input Parameter	Category C of the Near Surface Code [17] (NHMRC)				Determination of Individual Radionuclide Activity Concentration of Bulk NORM Waste		

* Individual radionuclide Activity Concentration Limits for Category C Waste as per the Near Surface Code [16] but calculated for an Institutional Control Period (ICP) of 300 years

[#] Conditions of an Arid and Remote site as per TRS No 141 [15]

[@] Sandy Ridge Site Specific Conditions

^ Assumption on cover material to be less penetrable by radon

[a] All pathways related to contaminated water usage removed, also for radon from water

8 ASSESSMENT RESULTS AND DISCUSSION

The following section discusses the results obtained through first principal calculations and RESRAD modelling for each of the Scenarios described in Section 7.

8.1 SCENARIO 1: HUMAN INTRUSION NEXT TO THE SHAFT CONTAINING CATEGORY B SEALED RADIOACTIVE SOURCES

The Activity Concentration at the end of the ICP was calculated using the following formula

$$\boxed{(A) = A_0 e^{-\lambda t}}$$

Where:
A = Activity remaining in the radioactive material after time (t) from when the initial activity was measured (at time of disposal) (GBq)
A_0= Initial Activity of the radioactive material (time of disposal) (GBq)
e = Base of the natural logarithm
λ = Decay constant (ln2/T½) and ln2 is equal to the constant 0.693
t = Time since the initial activity was measured (days)

The Unshielded dose rate was calculated by using the following formula.

$$\boxed{\text{Unshielded dose rate: } I_0 = \Gamma\ A / d^2 = \Gamma \text{ x Activity / (distance from waste source)}^2}$$

Where:
I_0= intensity (or dose rate) before shielding (mSv/h)
Γ= Specific Gamma Ray Constant (mSv/h) at 1 m from a source per 1 GBq activity of the source
A = Activity of the source (GBq)
d = distance from the source (m) {assumed as 0.1 m / 10 cm}

The Shielded dose rate was then calculated as follows:

$$\boxed{\text{Shielded dose rate:} \qquad I = I_0 / 2^n}$$

Where:
I = intensity (or dose rate) after shielding (mSv/h)
I_0= intensity (or dose rate) before shielding (mSv/h)
n = number of HVL in shielding material

Dose received on the outside of the shaft with shielding in place was calculated by multiplying the shielded dose rate (I) calculated with the assumed exposure time (40 hours).

The results are summarised in the table below and given in full in Appendix 1 of this report.

As can be seen from results given in Table 5, the shielding provided from concrete in drum, steel around drums and concrete in shafts is sufficient to shield the radiation from all sources assessed except high activity Caesium-137 sources. By adding 0.0255m lead shielding (as found in standard source casings) the dose rate is further reduced from 0.16 mSv/hr to 0.02mSv/hr. With the assumed 40 hours exposure the dose is 0.63mSV. This is well below the public dose limit of 10 mSv/year considered as the threshold for human intrusion scenarios. Given the conservative nature of the assessment and the low probability of event occurring it can be concluded that the risk is sufficiently controlled.

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Table 5: Scenario 1 exposure assessment results summary

Isotope	Half Life y (years) d (days)	Specific Gamma Ray Constant	Source Activity (GBq)		I_0 Unshielded Dose Rate (mSv/h)#	I shielded Dose Rate (0.485 m concrete and 0.0013 steel) (mSv/h)	I shielded Dose Rate (concrete steel and lead casing of 0.0255 m) (mSv/h)	Dose 40 Hours exposure time
		mSv/hr/GBq at 1 meter	Initial *	After 100 y	After 100 y	After 100 y	After 100 y	(mSv)
Americium-241	432.17 y	8.48E-02	2.00E+01	1.70E+01	1.44E+02	0	0	0
Caesium-137	30.07 y	1.03E-01	2.00E+02	2.00E+01	2.06E+02	0.18	0.02	0.63
Californium-252	2.6 y	1.13E-02	20	5.31E-11	6.01E-11	0	0	0
Cobalt-60	5.27 y	3.70E-01	5.40E-02	1.05E-07	3.89E-06	0	0	0
Iridium-192	73.8 d	1.60E-01	2.00E+01	2.81E-148	4.50E-147	0	0	0
Radium-226	1,600 y	3.27E-04	1.00E+00	9.58E-01	3.14E-02	0	0	0
Selenium-75	120 d	2.32E-01	3.70E-01	1.06E-92	2.46E-91	0	0	0
Thulium-170	129 d	1.67E-03	7.40E+03	5.15E-82	8.62E-83	0	0	0
Ytterbium-169	32 d	8.84E-02	3.70E+02	0.00E+00	0.00E+00	0	0	0

8.2 SCENARIO 2 AND 3: HUMAN INTRUSION- LIVING ON EXPOSED BULK WASTE AT ACTIVITY CONCENTRATION LEVELS OF CATEGORY A AND C

Table 6 Summarises the RESRAD modelling results for Scenarios 2 and 3, In the unlikely case where humans would reside on top of exposed bulk waste of category A, a total dose of 112 mSv/y is incurred from occupancies considered being residential (RESRAD default). The dose received is directly proportional to the duration of exposure. Occupancy of 5,870 hours/year would reduce the total maximum dose to 100 mSv/y and 587 hours/year would reduce total maximum dose to 10 mSv/y.

From Scenario 3 it was shown that a maximum total dose of 10,170 mSv/y is incurred at 0.6 years after intrusion at occupancies considered being residential (RESRAD default). Occupancy of 65 hours/year would reduce the total maximum dose to 100 mSv/y and 6.5 hours / year would reduce total maximum dose to 10 mSv/y.

External gamma exposure was shown to be the highest contributor to total dose, followed by radon.

Table 6: RESRAD Results Scenario 2 and 3

Model Output	Scenario 2	Scenario 3
Maximum Dose (mSv/y)	111.9	10170
Time of Maximum Dose (years after ICP)	0.589	0.602
Gamma at Max Dose	71.09	6100
Dust at Max Dose	0.8173	80.15
Radon at Max Dose	38.06	3801
Soil ingestion at Max Dose	1.956	186.8
Total Dose at Time 0	108.7	9848
Gamma at Time 0	67.92	5782
Dust at Time 0	0.8141	79.83
Radon at Time 0	38.06	3801
Soil ingestion at Time 0	1.936	184.8

In reality, the risk is mitigated by site selection of the facility and the cap design. The long term (10,000 plus years) performance of the cap has been modelled using both near-surface hydrogeological and erosion modelling software. The modelling has confirmed that the cap design is robust from both water infiltration and erosion aspects ad therefore it is concluded that it is implausible for the exposure to occur.

8.3 SCENARIO 4: RECREATIONAL VISITOR TO THE SITE POST CLOSURE

From Scenario 4 it was shown that a maximum total dose of 6.2×10^{-7} mSv/y is incurred only at 100,000 years after closure, indicating that for the expected land-use post institutional control, no risk to human receptors are foreseen, given that the possibility of intrusion is mitigated through engineering controls. This exposure rate is determined by the RESRAD calculation using the assumption that 5 m of erosion has occurred at the site. Given the geological properties and climate at the site, this calculation scenario is extremely unlikely.

Table 7: RESRAD Results for Scenario 4

Model Output	Scenario 4
Maximum Dose (mSv/y)	6.20E-07
Time of Maximum Dose (years after ICP)	1.00E+05
Gamma at Max Dose	3.59E-09
Dust at Max Dose	0
Radon at Max Dose	6.16E-07
Total Dose at Time 0	0
Gamma at Time 0	0
Dust at Time 0	0
Radon at Time 0	0

8.4 SCENARIO 5: WASTE ACCEPTANCE CRITERIA - CONCENTRATIONS LIMITS FOR NORM

The RESRAD (Onsite) code was used, to determine radionuclide activity concentration levels in bulk NORM wastes which would give rise to conditions as specified above for post closure and intrusion scenarios. Table 8 summarizes the radionuclide restrictions that should be applied in the Waste Acceptance Criteria (WAC) for the Facility for the disposal of NORM bulk wastes.

For bulk NORM wastes having mixtures of radionuclides, an additional constraint should be adhered to so that the total dose from all the radionuclides should not exceed relevant dose limits or constraints. This is referred to as the summation rule and requires the following constraint:

$$\boxed{\sum_i Q_i / Q_{i,l} <= 1}$$

Where Qi (Bq) is the actual activity of radionuclide to be disposed and Qi, l (Bq) is the activity limit for radionuclide if it were the only radionuclide to be disposed of.

Table 8 Waste Acceptance Criteria (WAC) for the Facility for bulk NORM waste

Radionuclides	Half Life	Individual Radionuclide Activity Concentration of Bulk NORM Waste) (Bq/g)
U-238	4.468 billion years	1.0E+05
U-234	246,000 years	2.0E+06
Th-230	75,380 years	1.2E+04
U-235	703.8 million years	2.2E+04
Pa-231	32,760 years	7.1E+03
Ra-226	1,600 years	1.8E+03
Th-232	14.05 billion years	1.1E+03

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9 CONCLUSIONS

As can be seen from Scenario 1 results, the shielding provided from concrete in drum, steel around drums and concrete in shafts, is sufficient to shield the radiation from all sources assessed except high activity Caesium-137 sources. By adding 0.0255m lead shielding (as found in standard source casings) the dose rate is further reduced from 0.16 mSv/hr to 0.02mSv/hr. With the assumed 40 hours exposure the dose is 0.63mSV. This is well below the public dose limit of 1mSv/year. Given the conservative nature of the assessment and the low probability of event occurring it can be concluded that the risk is sufficiently controlled.

In the unlikely case where humans would reside on top of exposed bulk waste of category A, a total dose of 112 mSv/y is incurred from occupancies considered being residential (RESRAD default). The dose received is directly proportional to the duration of exposure. Occupancy of 5,870 hours/year would reduce the total maximum dose to 100 mSv/y and 5, 87 hours / year would reduce total maximum dose to 10 mSv/y.

From Scenario 3 it was shown that a maximum total dose of 10,170 mSv/y is incurred at 0.6 years after intrusion at occupancies considered being residential (RESRAD default). Occupancy of 65 hours/year would reduce the total maximum dose to 100 mSv/y and 6.5 hours/year would reduce total maximum dose to 10 mSv/y.

External gamma exposure was shown to be the highest contributor to total dose, followed by radon.

From Scenario 4 it was shown that a maximum total dose of 6.2×10^{-7} mSv/y is incurred only at 100,000 years after closure, indicating that for the expected land-use post institutional control, no risk to human receptors are foreseen, given that the possibility of intrusion is mitigated through engineering controls.

The RESRAD (Onsite) code was used, to determine radionuclide activity concentration levels in bulk NORM wastes which would give rise to conditions as specified above for post closure and intrusion scenarios. These values were adopted In the WAC for NORM waste.

10 DEFINITIONS & ACRONYMS

Activity concentration – means the concentration of a radioactive substance in any particular material expressed in terms of the activity of the radionuclide in Becquerel per kilogram of the material.

Biosphere – that part of the environment that is normally inhabited by living organism and is taken generally to include those elements of the environment, including groundwater, surface water and marine resources, that are used by people or accessible to people.

Category A waste – as defined in the near surface code (ARPANSA 1992). Category A waste covers solid waste with radioactive constituents, mainly beta or gamma emitting radionuclides, whose half-lives are considerably shorter than the institutional control period. The radioactivity will decay substantially during this period. Long-lived alpha-emitting radionuclides should only be present at very low concentrations. This category of waste will comprise, predominantly, lightly contaminated or activated items such as paper, cardboard, plastics, rags, protective clothing, glassware, laboratory trash or equipment, certain consumer products and industrial tools or equipment. It may also comprise lightly contaminated bulk waste from mineral processing or lightly contaminated soils.

Category B wastes - as defined in the near surface code (ARPANSA 1992) includes solid waste and shielded sources with considerably higher activities of beta- or gamma-emitting radionuclides than Category A waste. Long-lived alpha-emitting radionuclides should be at relatively low levels. This category of waste will comprise, typically, gauges and sealed sources used in industry, medical diagnostic and therapeutic sources or devices, and small items of contaminated equipment.

Category C waste – as defined in the near surface code (ARPANSA 1992). includes solid waste containing alpha-, beta- or gamma-emitting radionuclides with activity concentrations similar to those for Category B. However, this waste typically will comprise bulk materials, such as those arising from downstream processing of radioactive minerals, significantly contaminated soils, or large individual items of contaminated plant or equipment for which conditioning would prove to be impractical.

Characterisation of waste – determination of the physical, chemical and radiological properties of the waste to establish the need for further adjustment, treatment, conditioning, or its suitability for further handling, processing, storage or disposal.

Dose Rate – the average level of dose that any material or biota is exposed to over time (typically measured in mSv/h).

Engineered barrier – means a feature made or altered by humans which delays or prevents radionuclide migration from the waste or the disposal structure into its surroundings; it may be part of the waste package or part of the disposal structure.

Half-life ($t^{1/2}$) – is the time taken for the activity of a radionuclide to decrease to 50% of its initial value.

Half-value layers (HVL) - One half-value layer is defined as the amount of shielding material required to reduce the radiation intensity to one-half of the unshielded value.

Institutional control period (ICP) – control of a waste site by an authority or institution designated under the law of a country. This control may be active (monitoring, surveillance and remedial work) or passive (land use control) and may be a factor in the design of a nuclear facility (e.g. a near surface repository).

Intrusion – inadvertent or intentional, means the process by which living organism, including humans, may come in contact with disposed or stored waste.

Member of the public – means a person who is exposed only incidentally to radiation as a consequence of the disposal of radioactive waste at a site or the operation of a disposal facility. Public exposure may occur through inadvertent intrusion or from dispersal of radioactive contaminants from the site.

Near surface disposal – or shallow ground burial means the disposal of radioactive waste in structures located below and/or above the natural ground surface (within approximately 30 metres of it) and covered by layer(s) of natural and/or manufactured materials.

NORM – means Naturally Occurring Radioactive Material – all the radionuclides contained in NORM occur in the natural environment.

Pathway – means a process, or series of processes, by which radionuclides are transferred through the environment.

Scenario – means a possible series of events or conditions which describe means of human intrusion or other contact with disposed waste after the closure of the site and following the institutional control period.

Sealed source – means controlled material permanently contained in a capsule, or closely bound in a solid form, that is strong enough to be leak-tight for (a) the intended use of the controlled material and (b) any foreseeable abnormal events likely to affect the controlled material.

Storage – means the emplacement of waste in a facility with the intent and in a manner such that it can be retrieved at a later time.

Waste acceptance criteria (WAC) – quantitative or qualitative criteria specified by the regulatory body, or specified by an operator and approved by the regulatory body, for radioactive waste to be accepted by the operator of a repository for disposal, or by the operator of a storage facility for storage. Waste acceptance requirement might include, for example, restrictions on the activity concentration or the total activity or particular radionuclides (or type of radionuclide) in the waste or requirements concerning the waste form or waste package.

Waste disposal – means the placement of radioactive waste in a structure and in a manner such that there is no intention of retrieval.

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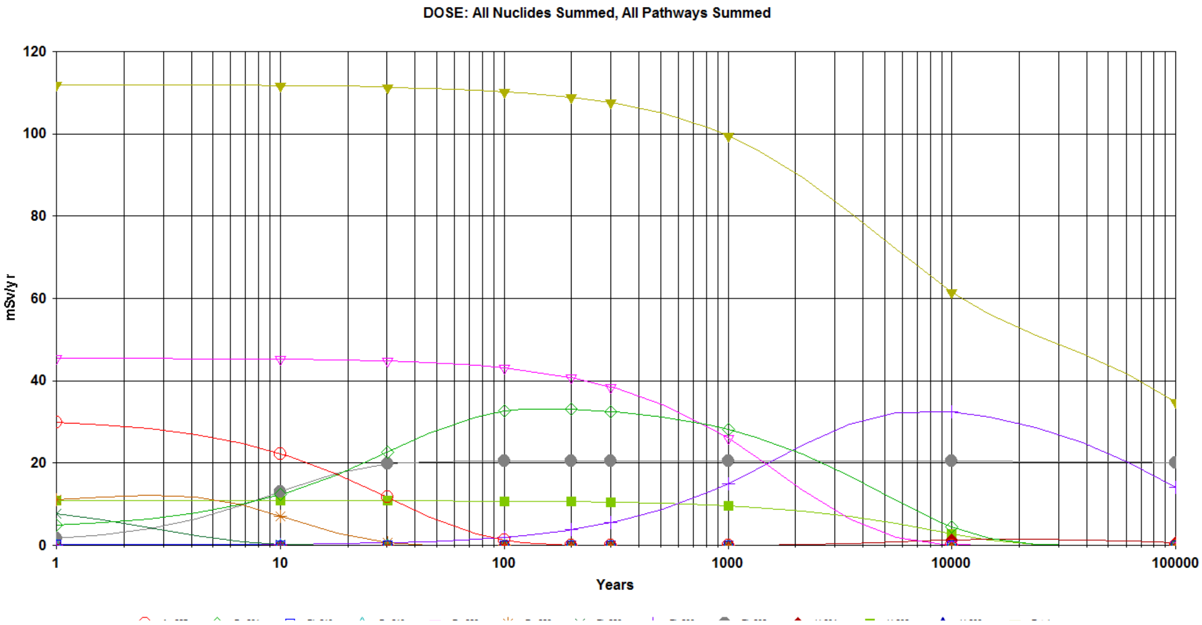
Appendix A
Scenario **1**
data

Table 9: Scenario 1 assessment data

Half Life Y (years) D (days)	Source Activity (GBq)		Γ	I_0 Unshielded Dose Rate (mSv/h)#		shielding concrete In drums	shielding steel from drums	shielding from lead casig	I shielded Dose Rate concrete (mSv/h)		I shielded Dose Rate steel (mSv/h)		I shielded Dose Rate lead casing 0.0255 m (mSv/h)	
	Initial *	100 y	mSv/hr/GBq at 1 meter	Initial *	After 100 y	0.285 m concrete in drums(n)	0.0013m steel around drums	lead casing 0.0255m	Initial *	After 100 y	Initial *	After 100 y	Initial *	After 100 y
432.17 y	2.00E+01	1.70E+01	8.48E-02	1.70E+02	1.44E+02	73.08	1.18	127.50	0.00	0.00	0.00	0.00		
30.07 y	2.00E+02	2.00E+01	1.03E-01	2.06E+03	2.06E+02	5.94	0.06	3.52	33.68	3.36	32.36	3.23	2.83	0.28
2.6 y	20	5.31E-11	1.13E-02	2.26E+01	6.01E-11	203.57	3.25	255.00	0.00	0.00	0.00	0.00		
5.27 ye	5.40E-02	1.05E-07	3.70E-01	2.00E+00	3.89E-06	4.71	0.06	2.08	0.08	0.00	0.07	0.00	0.02	0.00
73.8 d	2.00E+01	2.81E-148	1.60E-01	3.20E+02	4.50E-147	6.40	0.10	5.31	3.78	0.00	3.52	0.00		
1,600 y	1.00E+00	9.58E-01	3.27E-04	3.27E-02	3.14E-02	4.13	0.06	1.67	0.00	0.00	0.00	0.00		
120 d	3.70E-01	1.06E-92	2.32E-01	8.60E+00	2.46E-91	15.92	0.21	21.25	0.00	0.00	0.00	0.00		
129 d	7.40E+03	5.15E-82	1.67E-03	1.24E+03	8.62E-83	6.24	0.09	3.36	16.42	0.00	15.48	0.00	1.51	0.00
32 da	3.70E+02	0.00E+00	8.84E-02	3.27E+03	0.00E+00	6.24	0.09	3.36	43.37	0.00	40.87	0.00	3.99	0.00

Appendix B
Scenario 2
data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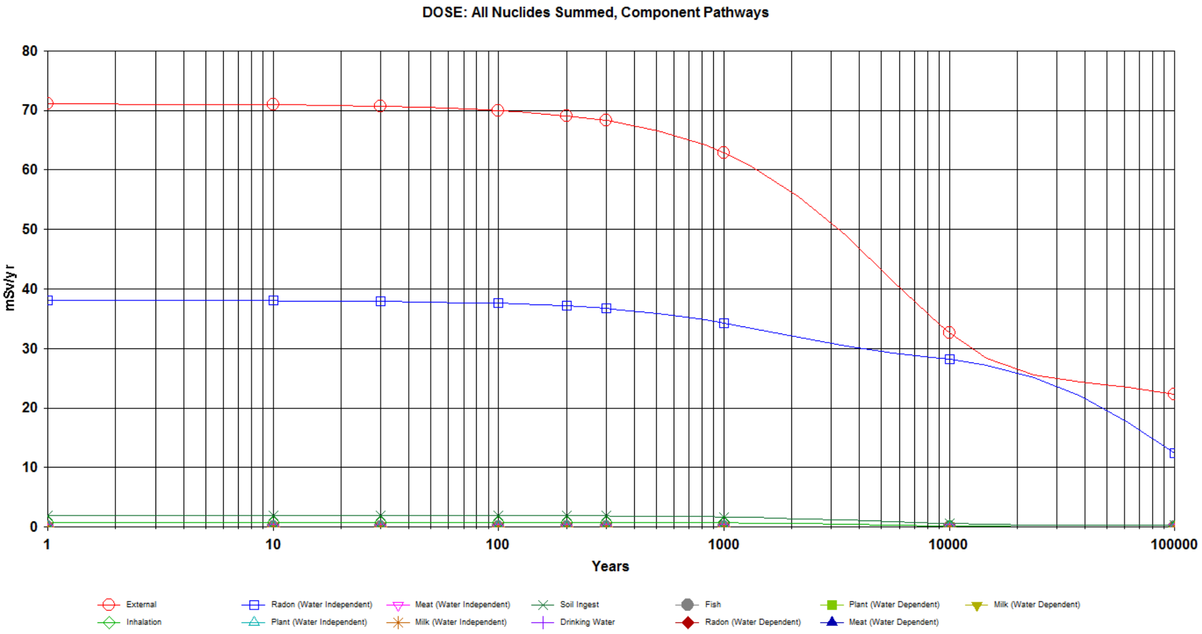
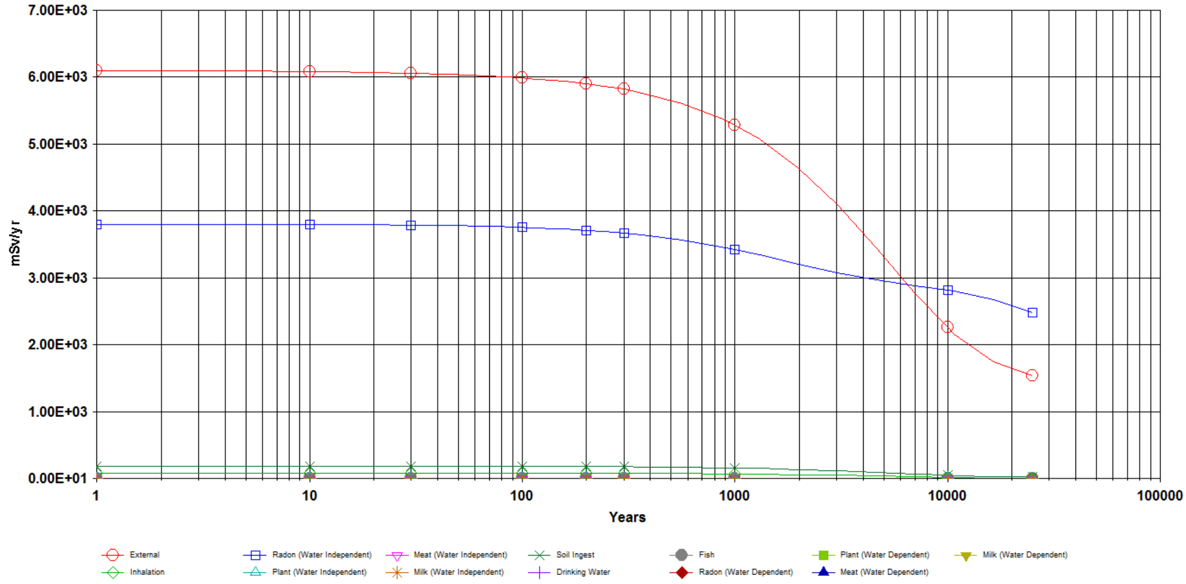
mSv/yr
Years


DOSE: All Nuclides Summed, Component Pathways
mSv/yr
Years
External
Inhalation
Radon (Water Independent)
Plant (Water Independent)
Meat (Water Independent)
Milk (Water Independent)
Soil Ingest
Drinking Water
Fish
Radon (Water Dependent)
Plant (Water Dependent)
Meat (Water Dependent)
Milk (Water Dependent)

Appendix C - Scenario 3 data

DOSE: All Nuclides Summed, Component Pathways



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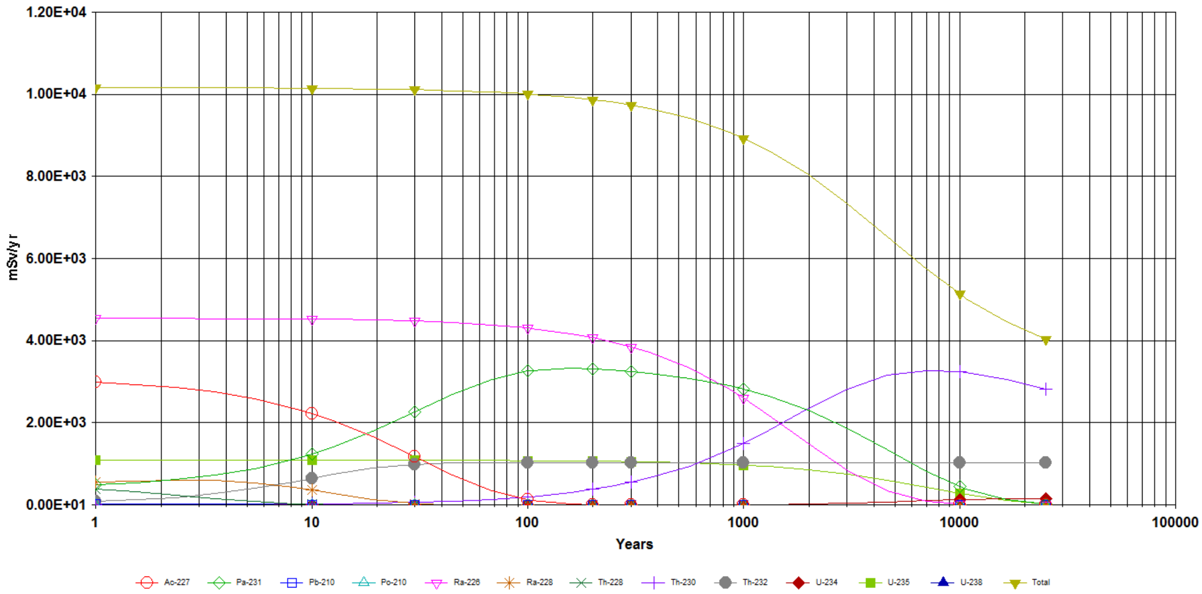
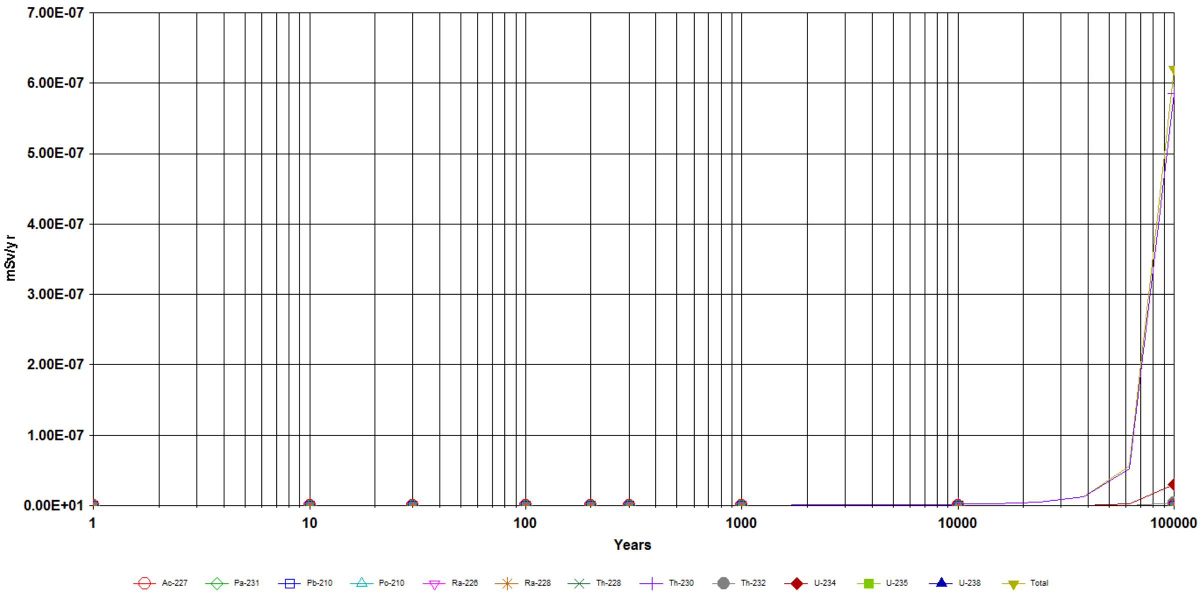


Appendix D
Scenario 4
data

DOSE: All Nuclides Summed, All Pathways Summed



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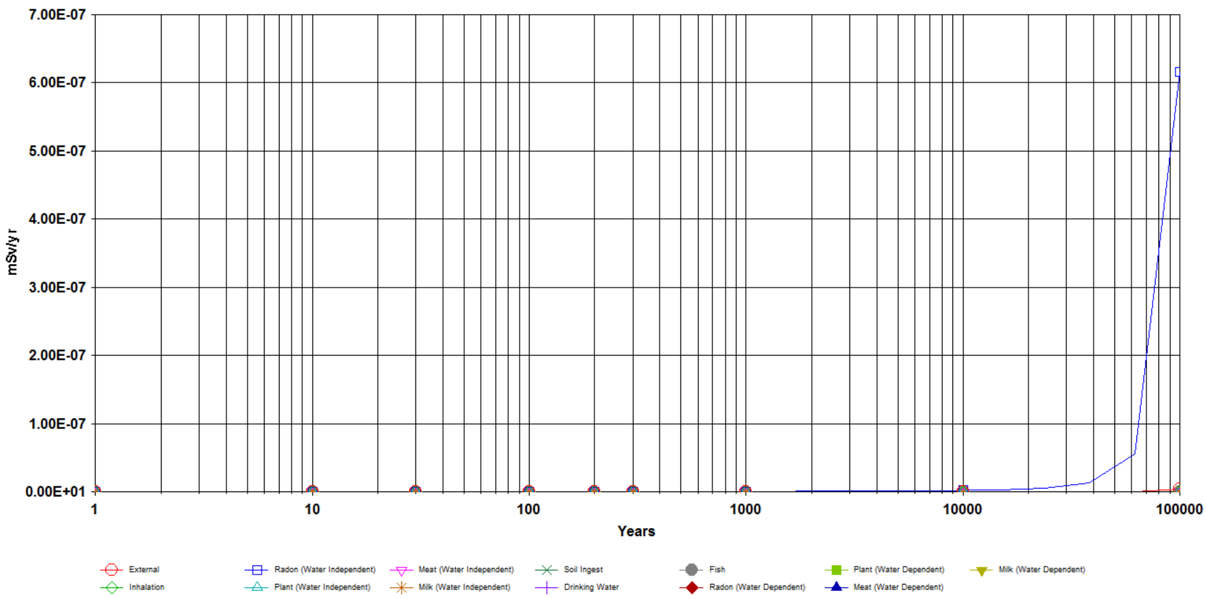

Appendix E
WAC data

Table 10:Determination of Individual Radionuclide Activity Concentration of Bulk NORM Waste

Nuclide	Category C Waste (Near Surface Code) – Activity Concentration Limit (Bq/g) for an institutional control period of 100 years					Waste Acceptance Criteria for the Sandy Ridge Facility (Determination of Individual Radionuclide Activity Concentration of Bulk NORM Waste)					
	Conceptual RESRAD Model; all pathways of exposure included; Conditions as per TRS No 141 for an Arid and Remote Site			RESRAD Sandy Ridge Conditions		RESRAD with Site Specific Conditions at Sandy Ridge: All pathways related to water Excluded, Intrusion, 1 day/year Occupancy					
	Category C Concentration Limit (Bq/g)	Post Closure 3.5 days/y (84 h/y), 5 m Cap	1 days/y (24 h/y), Intrusion	Post Closure 3.5 days/y (84 h/y), 7 m Cap	1 days/y (24 h/y), Intrusion	(Bq/g) to result in 10 mSv/y upon Intrusion	Modelled Dose Rate	(Bq/g) to result in 50 mSv/y upon Intrusion	Modelled Dose Rate	(Bq/g) to result in 100 mSv/y upon Intrusion	Modelled Dose Rate
		mSv/y @ 100y	mSv/y @ 100y	mSv/y @ 100y	mSv/y @ 100y		mSv/y @ 100y		mSv/y @ 100y		mSv/y @ 100y
U-238	10000	3.05E-25	3.05	0	1.06	1.00E+05	10.64	5.00E+05	53.2	1.00E+06	106.4
U-234	10000	1.02E-24	2.18	0	0.04	2.00E+06	8.62	1.00E+07	43.1	2.00E+07	86.2
Th-230	10000	2.26E-21	21.50	0	3.13	3.60E+04	11.28	1.80E+05	56.41	3.60E+05	112.8
U-235	10000	0	6.95	0	4.84	2.20E+04	10.65	1.10E+05	53.25	2.20E+05	106.5
Pa-231	10000	0	141.90	0	14.66	7.08E+03	10.38	3.54E+04	51.89	7.08E+04	103.8
Ra-226	500	2.41E-21	20.53	0	3.24	1.80E+03	11.66	8.00E+03	51.81	1.60E+04	103.6
Th-232	500	1.41E-18	31.62	0	4.58	1.10E+03	10.07	5.60E+03	51.27	1.12E+04	102.5

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