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ARPANSA Technical Report

Determining Radiological Screening Values for Recreational Activities around Water Bodies

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Executive Summary

The following report provides guidance on screening recreational water for radiological contaminates, including advice on when assessment is necessary, the operational process for screening, and screening values and the methodology used to determine screening values. For protection of members of the public from radiation in recreational water bodies a reference level of 10 mSv/year was selected in consultation with the Radiation Health Council and NHMRC advisory bodies. Screening values (Bq/L) are derived from an operational dose value of 1 mSv/year for gross alpha and beta concentrations in water, scenario specific gross alpha and beta concentrations, and radionuclide specific concentrations. Sediment screening values and a radon air concentration screening value are also provided for cases where water sampling alone may provide an insufficient overview of radionuclide concentrations in the environment surrounding the recreational body. The screening values are based on a selection of recreational activity scenarios which were designed to represent the broad range of popular recreational activities in and around water in Australia. The scenarios include swimming, surfing, diving, sailing, kayaking, fishing (both inclusive and exclusive of seafood ingestion), wading in shallow water, radon inhalation from a thermal spring, and sediment screening for time spent on the shore of a water body. These are not designed to capture every activity around recreational water but instead to offer enough variety in activities that most exposure situations can be represented by an available scenario. Each scenario is based on a member of the public (i.e. representative person) spending an extended period undertaking an activity in the same body of water. Ingestion, inhalation, and external exposure pathways have been identified for each scenario, the total effective dose is the sum of effective dose from all exposure pathways; the total effective dose is set as the operational dose value. Example case studies for following the operational process and a site-specific assessment example are provided in this report.

1. Introduction

Water based recreational activities are a popular pastime in Australia and recreational waters are highly valued by communities. In 2008, the National Health and Medical Research Council (NHMRC) released the *Guidelines for Managing Risks from Recreational Water* (NHMRC, 2008). The Guidelines aim to protect Australians from threats posed by the recreational use of coastal, estuarine, and freshwater environments. They are intended to ensure that recreational water environments are managed as safely as possible so that as many people as possible can benefit from using the water safely.

Radionuclides can enter recreational water through various environmental processes and pathways. These include natural sources like soil, rocks, and groundwater, or human activities such as former mine sites and historic nuclear weapon testing sites. Runoff from contaminated soil, caused by rainfall and irrigation, can wash radionuclides into nearby water bodies from industrial sites, and areas affected by past nuclear activities. Naturally occurring radionuclides come from cosmic or terrestrial sources. Cosmogenic radionuclides form in the upper atmosphere or in space and may attach to particles that are deposited onto the earth's surface. Terrestrial radionuclides include long-lived uranium and thorium radionuclides and their decay products, as well as radioactive potassium (K-40). The decay products of uranium and thorium include radioactive isotopes of uranium (U), thorium (Th), protactinium (Pa), radium (Ra), radon (Rn), polonium (Po), lead (Pb), bismuth (Bi), and actinium (Ac). These radionuclides have half-lives ranging from microseconds to billions of years and have existed in the environment since the formation of the earth. The radionuclides in the decay chain exist in a state of secular equilibrium (equal activities) unless disrupted by natural or anthropogenic processes. Controlled regulated discharges from nuclear facilities, including mining, milling of radioactive ores, and medical facilities, can introduce radionuclides into water bodies through direct release of wastewater. Natural erosion and weathering of rocks and soils release naturally occurring radionuclides into water bodies, a process that can be accelerated by human activities like construction.

A review of the small number of published research studies examining the presence of radioactivity in Australian recreational waters suggests that there are very few recreational water bodies that are likely to be contaminated by radionuclides at levels greater than those found naturally in the environment. These water bodies are typically in the vicinity (or catchment area) of current or former mine sites, or former nuclear weapons test sites. In addition, mineral and thermal springs or pools may contain higher concentrations of naturally occurring radionuclides from the underground rocks and minerals they pass through. Limited data is available for anthropogenic (human-made) radionuclides in recreational waters, such as stronium-90 (Sr-90) and caseium-137 (Cs-137). These can originate from controlled discharges by medical and industrial facilities, which are regulated by the respective state or territory. Human-made radionuclides can also be from former nuclear weapon testing and fallout, however fallout in the Southern Hemisphere is significantly lower than the Northern Hemisphere. Levels of these radionuclides can be expected to be negligible due to Australia's limited and regulated nuclear industry and protection measures for the public and the environment.

The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) is the Australian Government's primary authority on radiation protection and nuclear safety. ARPANSA regulates Commonwealth entities that use or produce radiation with the objective of protecting people and the environment from the harmful effects of radiation. ARPANSA undertakes research, provides services, and promotes national uniformity and the implementation of international best practices across all jurisdictions. Ensuring that recreational water meets safety standards, including the recommended reference level of 10 mSv/year, is crucial for protecting public health.

For radiation protection purposes, radiation exposure due to recreational water use is classified as an existing exposure situation. Currently there are no guidelines specifically derived for radiological water quality for recreational water use, either in the current NHMRC Guidelines (2008) or the recently revised WHO Guidelines (2021).

ARPANSA was engaged by the NHMRC to provide guidance on radiological hazards in recreational water. This report is to inform the development of screening values for radiological water quality in the updated Guidelines. This Technical Report includes an overview of the methods used to determine radiological screening processes for recreational water bodies.

1.1 Definitions

Recreational water: Any natural or artificial water bodies without a chemical disinfectant residual that might be used for recreating including coastal, estuarine and freshwater environments. Includes public, private, commercial and non-commercial recreational water sites. Includes unique unregulated sites such as wave pools, ocean- or river-fed swimming pools, artificial lagoons and water ski parks.

Recreational water use: Any designated or undesignated activity relating to sport, pleasure and relaxation that involves whole body contact or incidental exposure (through any exposure route) to recreational water (e.g. swimming, diving, boating, fishing).

Representative Person: An individual receiving a dose that is representative of the more highly exposed individuals in the population.

Total Effective Dose (E): The sum of effective doses from all exposure pathways. It is a measure of dose designed to reflect the amount of radiation detriment likely to result from the dose. The SI unit for effective dose is joule per kilogram (J kg-1), termed the sievert (Sv).

Reference level: The reference level is a measure of the annual effective radiation dose, which accounts for the potential health impacts for a person from the radiation exposure. The reference level for recreational water exposure recommended in this report is 10 millisieverts per year (mSv/y). If the reference level is exceeded appropriate invention measures should be implemented.

Operational dose value: The operational dose value is the level at which the screening value is determined. It is an indicator that further assessment of the recreational water body may be required. The operational dose value for recreational water is defined as 1/10 of the reference level (1 mSv/y).

Generic screening value: The generic screening value is a measurable concentration of gross alpha and beta activity in the recreational water body (Bq/L). It is based on a realistic worst case exposure scenario resulting in a dose greater than the operational dose value.

Scenario-specific screening value: A scenario-specific screening value is a measurable concentration of gross alpha and beta activity in the recreational water body (Bq/L). It is based on a realistic worst-case exposure for a representative recreational activity scenario (e.g. swimming, surfing) that results in a dose greater than the operational dose value.

Radionuclide specific screening value: A radionuclide specific screening value is a measurable concentration of activity from a particular radionuclide in a recreational water body (Bq/L). It is based on a realistic worst-case scenario from exposure to a specified radionuclide in the water body that would result in a dose greater than the operational level.

Site-specific parameters: Site-specific parameters are the characteristics unique to a specific recreational water site, for example the suspended sediment concentration. Site-specific parameters are used to when undertaking a site-specific dose assessment.

1.2 Radionuclides that may impact recreational activities around water bodies

Radionuclides occur naturally in the environment (e.g. uranium, thorium and potassium). Some radioactive compounds arise from human activities (e.g. from medical or industrial uses of radioactivity) and some natural sources of radiation are concentrated by mining and other industrial activities. By far the largest proportion of human exposure to radiation comes from natural sources of radiation, including cosmic radiation, external gamma radiation from rocks and soil, and from ingestion or inhalation of radioactive materials.

Elevated levels of radioactivity in recreational waters can result from:

- naturally occurring concentrations of radioactive material (e.g. radionuclides of the thorium and uranium series in water sources). This includes groundwater resources and mineral and thermal springs.
- technological processes involving naturally occurring radioactive materials (e.g. the mining and processing of mineral sands or phosphate fertilizer production), where there is contact with water bodies.
- manufactured radionuclides (produced and used in medicine or industry) that might enter recreational waters as a result of routine or incidental discharges or emergency situations.
- radionuclides released in the past into the environment from historic mining processes or former nuclear weapons testing.

Methods for radiological analysis of recreational water are provided in Annex 1. A more detailed assessment of a recreational water site include:

A. **Water Sampling:** Collecting and analysing whole water (i.e. unfiltered) samples to include both dissolved and particulate-bound radionuclides. This approach captures contributions from suspended sediments and sand, providing a more accurate representation of the total radionuclide load in the water body. Considering particulate-bound radionuclides is crucial as they can settle and accumulate in sediments.

B. **Sediment Sampling:** Collecting sediment samples for radionuclide concentrations, particularly if the radiation risk assessment of a recreational water body involves exposure scenarios where recreational water users come into contact with sediment or sand. Sediments can act as sinks for radionuclides, and their disturbance during recreational activities can lead to resuspension and increased exposure. Testing sediments helps in understanding the extent of contamination and the potential for exposure through direct contact or resuspension.

C. **Biota Sampling:** In fishing areas, collecting biota such as fish and other aquatic species (e.g. mussel, crabs) for radionuclide concentrations. This is essential to ensure these species are safe for consumption by recreational fishers. Monitoring biota helps in assessing the potential dietary exposure to radionuclides and ensuring food safety.

D. **Air Sampling:** Air sampling may be used in areas where there is exhalation of radionuclides from water bodies resulting radiation exposure from inhalation. This is of particular importance for thermal and mineral springs which may present an exposure to Radon due to inhalation.

1.3 A Risk Based Approach

A risk-based approach, which considers radiation protection principles of *justification* and *optimisation*, should be applied to any measures regarding radiation risk from recreational water bodies including the decision on whether monitoring is necessary.

Justification requires that any decision that changes a radiation exposure situation should do more good than harm. Reducing risk of potential exposure situation should achieve a sufficient individual or societal benefit to offset any detriment caused.

Optimisation requires that the likelihood and magnitude of exposures are kept as low as reasonably achievable, taking into account economic and societal factors. There is not a need to minimise exposures regardless of cost, rather the risks and benefits of any management should be balanced (ARPANSA, 2014).

The guidance presented in this report is intended solely for application in existing exposure situations. It is not appropriate to apply the reference levels and screening values provided to planned exposure situations. For planned exposures, dose limits should be determined in accordance with the ARPANSA *Code for Radiation Protection in Planned Exposure Situations* (ARPANSA, 2020) in consultation with relevant state or territory regulatory authorities.

1.3.1 Reference Level

In the case of existing exposure situations there will be some level of dose above which it is judged to be inappropriate to allow exposure to occur. This level of dose is used to set the **reference level**. Reference levels for existing exposure situations, are typically set between 1 and 20 mSv/year, as per ARPANSA RPS G-2 *Guide for Radiation Protection in Existing Exposure Situations (2017)* and IAEA GSR Part 3 (IAEA, 2014). The reference level is a benchmark for judging whether further protective actions are necessary and, if so, in prioritising their application. **For protection of members of the public from radiation in recreational water bodies a reference level of 10 mSv/year was selected.** This value was selected in consultation with the Radiation Health Committee and NHMRC advisory bodies. 10 mSv/year is considered to be a reasonable generic reference level for existing exposures; other situations where this reference level is applied include indoor radon exposure, and remediation of legacy and post-accident sites. Once an existing exposure is identified a site-specific reference level may be applied following stakeholder engagement and based on prevailing circumstances (ARPANSA, 2017).

1.3.2 Screening Values

The reference level is an annual effective dose to a representative person from radiation exposure from recreational water, which is not a direct measurable quantity. Screening values are established to provide a measurable indicator to identify if there is potential for the reference level is exceeded. The screening values are deliberately conservative and are derived such that they correspond to a radiation dose of approximately one tenth of the reference level, which is defined as the operational dose value. **Screening values are expressed in radioactivity per litre of unfiltered recreational water (Bq/L) and are based on the concentration of a single radionuclide type required to reach the operational dose value of 1 mSv/year**. If the screening values is not exceeded a decision maker can have confidence that the 10 mSv/year reference level will also not be exceeded, and no further analysis of the water body is required.

Exceeding a screening value does not indicate that a water body is unsafe for recreational use. Rather, if the screening value is exceeded, further assessment of the water body is recommended to better understand the radionuclide content of the water body and to allow for a more detailed risk assessment.

Generic screening, scenario specific screening and radionuclide specific screening levels are provided in this document. For freshwater bodies both the generic and radionuclide specific screening values can be applied, however for saltwater/brackish water only the radionuclide specific values are applicable as the total suspended solids are too large for effective gross alpha and beta screening.

1.3.3 Detailed Site-specific Assessment

More detailed assessment of the recreational water body should be conducted if generic gross alpha and beta screening values have been exceeded. This assessment could include:

- Collecting radionuclide specific water samples
- Performing a gross alpha/beta measurement of sediment on shore
- Collecting radionuclide specific sediment on shore samples
- Determine the site-specific sediment distribution coefficients (K_d)
- Determine the suspended sediment factor
- Determine site-specific habit date of a representative person

In any case, if a generic cautious assessment is used, then it should be ensured that its use does not unduly affect the optimisation process. Adopting cautious assumptions in the calculations that are likely to significantly overestimate the doses could lead to decisions that do not meet the radiation protection principle of optimisation.

1.4 Objective

In collaboration with the National Health and Medical Research Council (NHMRC), the objective of the report was to calculate and determine radiological screening values for recreational water.

1.5 Scope

The scope of this report was to:

- Identify and characterise exposure scenarios of recreational water use for the general Australian population
- Identify potential radiation exposure pathways from recreational activities around water bodies
- Develop a set a screening values for recreational water
    - Generic gross alpha and beta screening values
    - Scenario-specific screening values tailored to identified exposure scenarios
    - Radionuclide specific screening values
- Provide case studies to illustrate the dose assessment approach

2. Methods for Determining Screening Values

2.1 Dose Assessments

A radiological dose assessment is a method to assess and evaluate the potential dose to a representative person from a radiological source. The key steps include understanding of the potential radiological source(s) and all significant exposure pathways (i.e. ingestion, external gamma radiation) to which people could be exposed. The elements of a prospective dose assessment typically include: the selection of a source term, modelling of direct irradiation dispersion and transfer in the environment, identification of exposure pathways, identification of the representative person for normal operation, and assessment of the dose to the representative person.

This radiological dose assessment follows broad methodology from ARPANSA's Environmental Framework (ARPANSA, 2025) and the ARPANSA Guide to calculation of 'cumulative equivalent dose' (ARPANSA, 2017). As the objective of this assessment is to calculate the most conservative source term required to result in a pre-determined operational dose value (1 mSv) at an unknown recreational water body rather than a predicted dose from a known source term, the methods differ to account for this. The processes were modified assuming the dose to the representative person was the operational dose value of 1 mSv. The environment and habit data are not site-specific, so a variety of scenarios of recreational water activities were considered to represent a broad range of potential exposures. The duration and frequency of activities were designed to be conservative, but not excessive. Potential exposure pathways due to contaminated recreational water were identified for each exposure scenario with the sum of exposures from each pathway giving the total annual dose for the scenario. The concentration of a single radionuclide present in the recreational water which would result in the total dose reaching the operational dose value was determined for 57 different radionuclides (Appendix 1:). The screening level is the lowest concentration of a radionuclide required to reach the operational dose value.

2.2 Exposure Pathways

Exposure pathways describe the ways in which radioactive materials enter or impact the body. The potential health impact from a radiation exposure can vary depending on the exposure pathway, chemical and physical characteristics of the radioactive material and the age and gender of the exposed person. For recreational water exposure scenarios, exposure to radionuclides can occur through several pathways. In some situations, only a few pathways may be significant, while in others, multiple routes of exposure are considered depending on the nature and extent of contamination and the type of recreational activity.

External exposure pathways

External exposure occurs when radiation sources are located outside the body. This involves exposure to gamma radiation or high-energy beta particles, as alpha particles and low-energy beta particles lack the energy to penetrate the skin. Individuals may be externally exposed through immersion in contaminated water, contact with contaminated sediments, or proximity to submerged radioactive sources. Additionally, radioactive particles may adhere to the skin or clothing, continuing exposure the exposure after the event. Exposure depends on several factors, including the type and energy of the radiation, the distance from the source, the duration of exposure, and the surface area of the body in contact with the contaminated water body.

Internal exposure pathways

Internal exposure occurs when radioactive materials enter the body typically via ingestion or inhalation. In recreational water settings, this can happen through incidental ingestion of contaminated water, inhalation of radioactive aerosols or mist, consumption of contaminated aquatic organisms, or absorption through the skin or open wounds. Children and individuals with certain health conditions may be more susceptible to internal exposure due to differences in metabolism and physiology.

Table 1 – Description of Potential Exposure Pathways

Potential route of exposure		
Ingestion	Inadvertent ingestion of water	This occurs when individuals accidently swallow water that may contain contaminants. Very young children are particularly vulnerable to inadvertent ingestion of contaminated water. Inadvertent ingestion is a dominant exposure pathway for in-water activities, such as swimming and surfing, and may also occur on on-water activities such as kayaking and sailing.
	Inadvertent ingestion of sediment	The accidental ingestion of sediment due to suspended beach sand or sediment, or hand to mouth contact (especially for children) may result in the inadvertent ingestion of radionuclides which have been transported from the water body to the shoreline.
	Ingestion of seafood	Ingestion of contaminated sediment in the water body by marine biota will result in accumulation of radiological contaminants in the biota. Consumption of contaminated marine biota will result on the uptake of radionuclides in the body. Recreational activities which involve the gathering of marine biota, such as fishing or crabbing, are expected to include the ingestion of collected marine biota.

External	Immersion in water	Gamma radiation emitted from radionuclides in water can lead to external radiation exposure, through full or partial immersion in water, depending on the scenario. Full immersion can be assumed for swimming and diving, while partial immersion can be considered for surfing and fishing.
	External exposure to sediment or sand	An individual on the shore of a contaminated water body may receive external exposure to gamma radiation emitted from radionuclides attached to sediment on the shore.
Inhalation	Inhalation of sea spray	In areas where there is significant wind or surf, inhalation of suspended water particles in the air (sea-spray) may be a significant exposure pathway for activities in close proximity to the water body, such as surfing and kayaking.
	Inhalation of radon	Areas with high naturally occurring radionuclides, such as mineral and thermal springs, commonly have high levels of radon gas. Radon gas and its progeny is released from these water body bodies and can be a significant source of exposure for those consistently in proximity.

2.3 Exposure Scenarios

The development of exposure scenarios is necessary to comprehensively derive appropriate screening levels for radionuclides in recreational water. This is achieved by identifying and formulating various scenarios that would conservatively reflect the environmental conditions of a water body and the recreational activities that may occur there.

Exposure scenarios were designed to represent the broad range of popular recreational activities in and around water in Australia. Nine different activities were selected to become scenarios (Table 2). These are not designed to capture every activity around recreational water but instead to offer enough variety in activities that most exposure situations can be represented by an available scenario. Each scenario is based on a member of the public (i.e. representative person) spending an extended period undertaking an activity in the same body of water. The scenarios are designed to be conservative, but realistic and are chosen on the basis that the recreational activity is representative of the majority of the recreational activities at the water body being assessed.

Table 2 – Exposure Scenarios and Descriptions

Scenario	Description of exposure	Duration of activity
enHealth	This refers to the incidental ingestion of water during recreational activities such as swimming, surfing, or kayaking.	150 events per year (enHealth, 2012). 250 mL of water swallowed per swimming event (DeFlorio-Barker, et al., 2018).
Swimming - nominal		150 events per year (enHealth, 2012).

Swimming - extensive	This refers to the incidental ingestion of water and immersion in water during swimming.	250 mL of water swallowed per swimming event (DeFlorio-Barker, et al., 2018). 1 hour of water immersion per event (AUSPLAY, 2023a).
Fishing (recreational inshore)	Close proximity to a water body during fishing can result in external exposure from water shine and internal exposure from inhalation of sea-spray.	720 hours per year (i.e. 60 hours per month) (Pita, et al., 2022)
Fishing and Seafood Consumption*	An addition to the fishing scenario including the consumption of seafood caught.	720 hours per year (i.e. 60 hours per month) (Pita, et al., 2022)
Surfing	Inadvertent ingestion of water could occur during wipeouts or paddling. Inhalation of sea spray could occur with frequency motion and external contact with the water.	260 events per year (i.e. 5 days per week); 2 hours per event (AUSPLAY, 2023b). 170 mL water swallowed per event (Stone, Harding, Hope, & Slaughter-Mason, 2008).
Diving	Inadvertent ingestion may occur when diving; water may enter the mouth during mask cleaning or breathing. Full immersion in the water could result in external exposure to the skin.	160 events per year; 2 hours per event. 200 mL water swallowed per event (Schijven & de Roda Husman, 2006).
Sailing	Sailing can result in inadvertent ingestion of water through splashing or spray leading to swallowing small amounts of water. Direct skin contact with water and wet surfaces can result in external exposure.	100 hours in a year (Taverner Research Group, 2023). 20 mL water ingestion per event (Dorevitch, et al., 2011).
Kayaking	Kayaking may result in inadvertent ingestion of water that may be swallowed during paddling or capsizing. Sea spray may be inhaled during paddling in rough conditions. External exposure through skin contact with water and wet gear.	100 events per year; 4 hours per event (AUSPLAY, 2023c) 20 mL water ingestion per hour (Dorevitch, et al., 2011).
Wading	Spending time close to the water's edge, wading in shallow water. Sediment may be inadvertently ingested via hand-to-mouth contact or splashing. Skin contact with water especially in muddy or silty environments.	150 events per year (enHealth, 2012); 1 hour per event (AUSPLAY, 2023a) 30 mins of immersion in water 30 mins of external exposure from sediment 125 mL water ingestion per event (DeFlorio-Barker, et al., 2018) 25 mg of inadvertent sediment ingestion per event (IAEA, 2015)
Thermal Spring	Bathing in mineral-rich thermal springs could result in the inhalation of radon gas released from the water.	150 events per year; 2 hours per event (enHealth, 2012)

Beach*	Spending time at the beach close to the water's edge.	365 hours a year (AUSPLAY, 2023d).

* Dose from sediment from time spent on water body shore and consumption of seafood are out of scope for the NHMRC recreational water guidelines.

2.3.1 Habit Data for the Representative Person/ Member of the Public

The habits data used for deriving the generic and scenario-specific screening levels are detailed below.

EnHealth

The enHealth scenario is based on recommendations from the *Australian Exposure Factor Guide* (enHealth, 2012) and the World Health Organisation *Guidelines on Recreational Water Quality* (WHO, 2021). The reference scenario assumes 150 swimming events per year and only considers ingestion as the significant exposure route, with an inadvertent ingestion rate of 250 mL per event.

Swimming – nominal and extensive

The swimmer refers to a five-year-old, 10-year-old or an adult swimming in a natural water body[1]. Scenario specific habit data required is the annual time spent swimming and the average inadvertent ingestion rate during swimming. The annual exposure time for the nominal swimming scenario is based on the enHealth reference scenario which assumes 150 events per year (enHealth, 2012). The annual exposure time for the extensive swimming scenario (312 hours/year from a member of the public swimming 1 hour a day, 6 days a week) is derived from the average duration and top 4% of frequency in adults recreationally swimming from the 2019 AUSPLAY Swimming State of Play Report (AUSPLAY, 2023b). The assumed inadvertent ingestion rate of 250 mL/hour (DeFlorio-Barker, et al., 2018).

Fishing

The fisher refers to a five-year-old, 10-year-old or adult fishing while partially submerged in a natural water body. The annual exposure time (720 hours a year) is taken from a survey of recreational fisher habits by Pita et al. (2022) where the average reported fishing activity was 60 hours a month. The consumption of seafood from recreational fishing was not included as it is considered out of scope of the NHMRC recreational water guidelines.

Fishing and Seafood Consumption (Out of Scope of NHMRC Recreational Water Guidelines)

The fisher refers to an adult fishing while partially submerged in a natural water body and consuming fish which were caught from the water body. The scenario specific habit data used for this scenario is the annual exposure time and the portion of annual seafood intake which originates from the water body. The annual exposure time (720 hours a year) is taken from a survey of recreational fisher habits by Pita et al. (Recreational fishing, health and well-being: findings from a cross-sectional survey, 2022) where the average reported fishing activity was 60 hours a month. It was assumed that all of the fisher's total seafood intake comes from recreational fishing. IAEA TECDOC-1759 recommends using a generic annual seafood

[1] Excludes aquatic facilities using chemical disinfection including swimming pools, spas, splash parks, ornamental water sites

ingestion rate for adults of 65 kg/a, distributed between 50 kg/a of fish and 15 kg/a of crustaceans and molluscs (IAEA, 2015).

Surfing

The surfing scenario refers to a five-year-old, 10-year-old, or adult, surfing recreationally at the same beach year-round. Scenario specific data required is the time spent surfing and the inadvertent ingestion rate. The annual exposure time (641.3 hours/year from a member of the public surfing five days a week for an average of 2 hours) is derived from the average duration and top 4% of frequency in adults recreationally surfing from the 2019 AUSPLAY Surfing State of Play Report (AUSPLAY, 2023b). The assumed inadvertent ingestion rate is 170 mL/day is the average inadvertent ingestion intake determined in a study by Stone et al. (2008)

Diving

The diving scenario refers to a five-year-old, 10-year-old, or an adult diving in the same location year-round. The scenario specific data used is the time spent diving and inadvertent ingestion rate. The annual exposure time (320 hours/year from a member of the public participating in 160 dives per year) and the ingestion rate of 0.2 L per dive are the maximum reported dives per year from a recreational diver and the maximum inadvertent water ingestion per dive from a survey conducted by Schijven et al (Schijven & de Roda Husman, 2006).

Sailing

The sailing scenario refers to a 5-year-old, 10-year-old, or adult sailing recreationally for 100 hours a year on the same water body. The annual exposure duration of 100 hours a year is based on information from a 2023 NSW Recreational Boater Survey (Taverner Research Group, 2023). The inadvertent ingestion of water rate of 0.015 L per hour is the upper estimate of water ingestion during limited contact recreational activities on surface waters in a study by Dorevitch et al. (Dorevitch, et al., 2011).

Kayaking

The kayaking scenario refers to a 5-year-old, 10-year-old, or adult recreational kayaker. The annual exposure time (400 hours/year from a member of the public kayaking 100 times a year for an average of 4 hours) is derived from the average duration and top 5% of frequency in adults recreationally kayaking from the 2023 Ausplay Canoeing/Kayaking Report (AUSPLAY, 2023c). The inadvertent ingestion of water rate of 0.015 L per hour is the upper estimate of water ingestion during limited contact recreational activities on surface waters in a study by Dorevitch et al. (Dorevitch, et al., 2011).

Wading

The wading scenario refers to a 1-year-old, 5-year-old, 10-year-old, or adult spending time close to the waters edge, wading in shallow water. The annual exposure time is 150 hours/year from 150 events per year with an average duration of 1 hour per event (enHealth, 2012). It is assumed that for half of the time spent wading the reference person is immersed in water and inadvertently ingesting water at a rate of 250 mL/event (DeFlorio-Barker, et al., 2018). For the other half of the scenario, the reference person is on the shore edge receiving external exposure from radionuclides in the coastal sediment, and internal exposure from inhalation of sea-spray and inadvertent ingestion of coastal sediment (50 mg/h for the 1-year-old and

5 mg/h for all other ages (IAEA, 2015)). The Radionuclide concentration of the coastal sediment is assumed to be a fraction of 10 lower than that in suspended particles in the water (IAEA, 2015).

Thermal Spring

Thermal and mineral springs commonly contain high levels of naturally occurring radionuclides from the long-lived uranium and thorium, and their decay products. Radon is present in both uranium and thorium decay chains, and as noble gas is released from the water body into the surrounding air. The transfer coefficient of Rn-222 dissolved in water to the Rn-222 concentration in the air around the thermal spring is assumed to be 2×10^{-3} (Nugraha, et al., 2021). The transfer coefficient from a study of radon activity concentrations in natural hot spring water in Indonesia by Nugraha et al. has been adopted rather than the UNSCEAR recommendation of 10^{-4} (UNSCEAR, 2000) as the higher transfer coefficient is likely a result of water mixing due to occupants of the hot springs and provides are more conservative approach. For indoor pools and areas with poor ventilation, the air concentration of radon should be measured to account for radon build-up. The assumed occupancy of a thermal spring for recreational purposes is 150 events per year, the average duration of an event is 2 hours (enHealth, 2012).

Beach

The beach scenario refers to a 1-year-old, 5-year-old, 10-year-old, or adult occupying a beach shore for 1 hour a day, 365 days a year (AUSPLAY, 2023d). External dose from the coastal sediment and inadvertent ingestion of the sediment are the considered exposure pathways for this scenario. The inadvertent ingestion rate of sand is 50 mg/h for the 1-year-old and 5 mg/h for all other ages (IAEA, 2015). The beach scenario does not involve direct contact with the recreational water body, considering exposure pathways only from shore sediment, and is therefore out of scope of the NHMRC guidelines. Screening levels for the beach scenario are provided for the shore sediment in Bq per kg.

Table 3 – Exposure Pathways for each Exposure Scenario

Exposure Pathway/Scenario	Immersion	Inadvertent Ingestion	Inhalation	External Sediment	Ingestion of Sediment	Ingestion of Seafood*	Inhalation of Radon	Total Effective Dose Calculation
enHealth		X						$E = E_g$
Swimming	X	X						$E = E_m + E_g$
Fishing	X		X					$E = E_m + E_h$
Surfing	X	X	X					$E = E_m + E_h + E_g$
Diving	X	X						$E = E_m + E_g$
Sailing	X	X	X					$E = E_m + E_h + E_g$
Kayaking	X	X	X					$E = E_m + E_h + E_g$
Wading	X	X	X	X	X			$E = E_m + E_h + E_g + E_e + E_s$
Thermal Spring							X	$E = E_r$
Beach*				X	X			$E = E_e + E_s$
Fishing and Seafood Consumption*	X		X			X		$E = E_m + E_h + E_f$
Symbol for Assessment	m	g	h	e	s	f	r	

*Dose from sediment from time spent on water body shore and consumption of seafood are out of scope for the NHMRC recreational water guidelines.

2.4 Calculation of Screening Values

The total effective dose (E_{total}) to the representative person is the sum of all exposure pathways considered for a scenario, as shown in Equation 1. For example, the total effective dose for the surfing scenario would be the sum of exposure from immersion, inhalation and ingestion (Table 3). The maximum total effective dose is defined as the operational dose value of 1 mSv/y.

Equation 1

$$E_{total} = \sum_{j} E_j \leq 1\ mSv/year$$

Methods for determining effective dose from each exposure pathway were adapted from publications from the International Atomic Energy Agency (IAEA, 2001) (IAEA, 2015) (IAEA, 2018), the Radiological Impact Assessments from the Tokyo Electric Power Company Holdings, Inc. (TEPCO, 2022) and the Pacific Northwest National Laboratory (PNNL, 2024). It was assumed that only one radionuclide type contributed to the effective dose, Appendix 1: contains a list of all the radionuclides considered. The smallest concentration of the considered radionuclides and exposure scenarios that results in a dose equivalent to the operational dose value is taken to be the generic screening value. The smallest concentration of the considered radionuclides for each exposure scenarios that results in a dose equivalent to the operational dose value is taken to be the scenario specific screening value.

2.4.1 Dose coefficients

The International Commission on Radiological Protection (ICRP) has published dose coefficients for each radionuclide which consider the sensitivity of organs and tissues in the body, the biological half-life of the radionuclide and the type of radiation emitted. The dose coefficients include ingestion and inhalation coefficients from ICRP 119 (ICRP, 2012), water immersion and ambient dose from soil coefficients from ICRP 144 (ICRP, 2020), and sediment distribution coefficients and concentration factors for marine biota from IAEA TRS 422 (IAEA, 2004). Generally, the dose coefficient is higher in younger age groups.

The naturally occurring radionuclides with the highest dose coefficients for each of the exposure pathways are Ra-228 for ingestion, Th-228 for inhalation, Th-228 for immersion in water and U-235 for external dose from soil, all for an infant of 3 months according the ICRP age groups. The anthropogenic radionuclides with the highest dose coefficients are Sr-90 for ingestion, Cf-252 for inhalation, Sb-124 for immersion in water and Ag-110m for external dose from soil, all for an infant of 3 months. Further, the dose coefficients of the anthropogenic radionuclides were lower than the natural radionuclides, except for immersion in water and external dose from soil.

Potassium-40 is not included in the determination of committed effective doses. The human body maintains a relatively constant level of potassium, and hence a constant level of K-40. Therefore, an increase in the amount of K-40 ingested does not result in accumulation and, consequently, the dose due its presence has been determined to be 0.165 and 0.185 mSv/year for adults and children, respectively (UNSCEAR, 2000).

2.4.2 Immersion in Water

This exposure pathway considers the external dose received from immersion in contaminated water; the representative person may be fully or partially immersed in water depending on the scenario. Full immersion is assumed for the swimming and diving scenarios; partial immersion is assumed for the surfing and fishing scenarios as the representative person spends 50% of the activity time submerged. A dose-reduction factor of 0.5 is applied for external exposure for the kayaking and sailing scenarios (U.S. EPA, 2019), to account for the external exposure from the water surface. Immersion in water was calculated according to Equation 2.

Equation 2

$$E_m = C_w\, t\, DC_m\, f_m$$

Where:

E_m is the effective dose (mSv/y) from radiation while immersed in water.

C_w is the concentration of the radionuclide in water (Bq/L).

t is the annual exposure time (h/year) (Table 14).

DC_m is the effective dose conversion factor from gamma radiation from the radionuclide from water immersion (mSv/h)/(Bq/L) from ICRP 144 (ICRP, 2020).

f_m is the immersion factor, the fraction of time spent immersed in water during the activity (Table 15).

2.4.3 Inadvertent Ingestion of Water

Members of the public performing recreational activities in or on a water body may be exposed to aqueous or particulate radionuclides through inadvertent ingestion of water. The rate of inadvertent ingestion is dependent on the type of recreational activity. The values used for rate of ingestion for each activity are in Table 13. Effective dose from inadvertent ingestion was calculated according to 3.

Equation 3

$$E_g = C_w\, t\, H_w\, DC_g$$

Where:

E_g is the effective dose (mSv/y) from radioactive materials from ingestion of water.

C_w is the concentration of the radionuclide in water (Bq/L).

t is the annual exposure time (h/year) (Table 14).

H_w is the inadvertent ingestion of water rate (L/h) (Table 13).

DC_g is the committed effective dose factor from ingestion of a radionuclide (mSv/Bq) from ICRP 119 (ICRP, 2012).

2.4.4 Inhalation of Sea Spray

Inhalation of radionuclides entrained sea spray suspended in the air was considered as an exposure pathway for scenarios in which the representative person is expected to spend all or most of the exposure time above the surface of the water. The effective dose from inhalation of sea spray was calculated according to Equation 4. Sea spray (vapour in air component) was assumed to be present in air at an enhanced atmospheric concentration of 0.01 kg/m3.

Equation 4

$$E_h = C_w \, t \, R_S \left(\frac{C_s}{\rho_w}\right) DC_h$$

Where:

E_h is the effective dose (mSv/y) from radioactive materials from inhalation of seawater spray.

C_w is the concentration of the radionuclide in water (Bq/L).

t is the annual exposure time (h/year) (Table 14).

R_S is the respiration rate (L/h) (Table 16) (ICRP, 1995).

C_s is the air concentration of seawater spray (kg/m^3) (default value: 0.01 kg/m^3) (IAEA, 2015).

ρ_w is the density of seawater (kg/m^3) (default value: 1000 kg/m^3).

DC_h is the committed effective dose factor from inhalation of a nuclide (mSv/Bq) (ICRP, 2012).

2.4.5 Inhalation of Radon Gas

Inhalation of radon gas released from water was considered the dominant exposure pathway for the thermal spring scenario. Inhalation of radon and its progeny results in the deposition of radon progeny in the respiratory tract and the subsequent irradiation of the lungs (UNSCEAR, 2000). The effective dose due to inhalation of radon-222 and its progeny released from thermal water is calculated according to Equation 5. For recreational water bodies in a closed environment or with poor ventilation an assessment of radon levels in the water body should include a measurement of the air concentration to account for radon build-up. Equation 5a calculates the effective dose based on a measurement on Radon concentration in water, while 5b calculates the effective dose based on a measurement of Radon concentration in air.

Equation 5a

$$E_r = C_w \, r_{w-a} \, t \, DC_r$$

Where:

E_r is the effective dose (mSv/y) from the inhalation of radon-222 gas and progeny released from thermal water.

C_w is the concentration of the radionuclide in water (Bq/L).

t is the annual exposure time (h/year) (Table 14).

r_{w-a} is the ratio of the concentrations of radon in water and air (default value: 2×10^{-3}) (Nugraha, et al., 2021).

DC_r is the effective dose per exposure of Radon-222 gas and progeny indoors (default value: 1.3×10^{-2} (mSv/Bq)/(h/L)) with an average breathing rate of 1.2 m^3/h and an equilibrium factor of 0.4 (ICRP, 2017).

Equation 6b

$$E_r = C_w \, t \, DC_r$$

Where:

E_r is the effective dose (mSv/y) from the inhalation of radon-222 gas and progeny released from thermal water.

C_w is the concentration of the radionuclide in air (Bq/m^3).

t is the annual exposure time (h/year) (Table 14).

DC_r is the effective dose per exposure of Radon-222 gas and progeny indoors (default value: 1.3×10^{-5} (mSv/Bq)/(h/m^3)) with an average breathing rate of 1.2 m^3/h and an equilibrium factor of 0.4 (ICRP, 2017).

2.4.6 External Dose from Sediment

Radioactive material in a water body can be transported to the shoreline from suspended particles in the water. IAEA TECDOC-1759 assumes that the radionuclide concentration in coastal sediment is a factor of 10 lower than that in suspended particles (IAEA, 2015). Radionuclides deposited on the shore may lead to external exposure to members of the public on the shore. The effective dose due to external exposure from sediment is calculated according to Equation 7. Equation 6a calculates the effective dose based on a measurement on radionuclide concentration in water, while 6b calculates the effective dose based on a direct measurement of sediment.

Equation 7a

$$E_e = \frac{C_w \, t \, K_d \;\, \rho_s \, d_s \, DC_e \, x}{(1 + 0.001 \, K_d \, S)}$$

Where:

E_e is the effective dose (mSv/y) from external radiation from sediment.

C_w is the concentration of the radionuclide in water (Bq/L).

t is the annual exposure time (h/year) (Table 14).

K_d is the sediment distribution coefficient in water (L/kg) (IAEA, 2004).

DC_e is the effective dose conversion factor from gamma radiation from a nuclide from sediment (mSv/h)/(Bq/m^2) (ICRP, 2020).

ρ_s is the density of coastal sediment (default value: 1500 kg/m^3) (IAEA, 2015).

d_s is the effective thickness of coastal sediment (default value: 0.1 m) (IAEA, 2015).

S is the suspended sediment concentration (default value: 10^{-5} kg/m^3) (IAEA, 2001).

x is the fraction of suspended particles in the water present in the coastal sediment (default value: 0.1) (IAEA, 2015).

Equation 8b

$$E_e = C_c \, t \, \rho_s \, d_s \, DC_e$$

Where:

E_e is the effective dose (mSv/y) from external radiation from sediment.

C_c is the concentration of the radionuclide in coastal sediment (Bq/kg).

t is the annual exposure time (h/year) (Table 14).

ρ_s is the density of coastal sediment (default value: 1500 kg/m^3) (IAEA, 2015).

d_s is the effective thickness of coastal sediment (default value: 0.1 m) (IAEA, 2015).

DC_e is the effective dose conversion factor from gamma radiation from a nuclide from sediment (mSv/h)/(Bq/m^2) (ICRP, 2020).

2.4.7 Inadvertent Ingestion of Sediment

Inadvertent ingestion of sediment is a common exposure pathway for a member of the public spending time on a shore. The effective dose from ingestion of sediment is shown in Equation 9. Equation 7a calculates the effective dose based on a measurement on radionuclide concentration in water, while 7b calculates the effective dose based on a direct measurement of sediment.

Equation 9a

$$E_s = \frac{K_d \, d_s \, DC_g \, t \, H_s \, C_w \, x}{L_B (1 + 0.001 \, K_d \, S)}$$

Where:

E_s is the effective dose (mSv/y) from ingestion of sediment.

t is the annual exposure time (h/year) (Table 14).

K_d is the sediment distribution coefficient in water (L/kg) (IAEA, 2004).

DC_g is the committed effective dose factor from ingestion of a radionuclide (mSv/Bq) from ICRP 119 (ICRP, 2012).

C_w is the radionuclide concentration in water (Bq/L)

H_s is the ingestion of sediment (kg/h) (Table 17) (IAEA, 2015).

L_b is the thickness of the sediment layer (default value: 0.01 m) (IAEA, 2015).

d_s is the effective thickness of coastal sediment (default value: 0.1 m) (IAEA, 2015).

S is the suspended sediment concentration (default value: 10^{-5} kg/m^3) (IAEA, 2001).

x is the fraction of suspended particles in the water present in the coastal sediment (default value: 0.1) (IAEA, 2015).

Equation 10b

$$E_s = \frac{d_s \, DC_g \, t \, H_s \, C_c}{L_B}$$

Where:

E_s is the effective dose (mSv/y) from ingestion of sediment.

t is the annual exposure time (h/year) (Table 14).

DC_g is the committed effective dose factor from ingestion of a radionuclide (mSv/Bq) from ICRP 119 (ICRP, 2012).

C_c is the radionuclide concentration in coastal sediment (Bq/kg)

H_s is the ingestion of sediment (kg/h) (Table 17) (IAEA, 2015).

L_b is the thickness of the sediment layer (0.01 m) (IAEA, 2015).

d_s is the effective thickness of coastal sediment (0.1 m) (IAEA, 2015).

2.4.8 Ingestion of Seafood

Ingestion of marine biota from a recreational fishing area is an expected exposure pathway as a result of recreational fishing. Ingestion of contaminated sediment in the water body by marine biota will result in accumulation of radiological contaminants in the marine biota. The effective dose from the ingestion of seafood is calculated according to Equation 11.

Equation 11

$$E_f = \frac{C_w \, DC_g \, CF \, N}{1 + 0.001 \, K_d \, S}$$

Where:

E_s is the effective dose (mSv/y) from the ingestion of seafood.

C_w is the concentration of the radionuclide in water (Bq/L).

t is the annual exposure time (h/year) (Table 14).

DC_g is the committed effective dose factor from ingestion of a radionuclide (mSv/Bq) from ICRP 119 (ICRP, 2012).

DC_f is the concentration factor for marine biota (fish or crustaceans) in L/kg (IAEA, 2004).

N is the annual seafood ingestion in kg/year (Table 18).

3. Screening Values

3.1 Calculation of Screening Values

The most conservative or 'worst case' radionuclide and scenario were selected as screening levels for gross alpha and beta. The gamma concentration limit was divided into three screening levels as it is more practical to differentiate between gamma emitting radionuclides during screening.

3.1.1 Gross Alpha and Beta

Table 4 – Generic (Gross Alpha and Beta) Screening Values for all exposure scenarios

	Alpha (Bq/L)	Beta (Bq/L)
Excluding Scenarios with Seafood Consumption	1.4	1.3
Including Scenarios with Seafood Consumption	0.5	0.2
Sediment (Bq/kg)	3110	750
Radon^	130	
Radon Air Concentration (Bq/m^3)	250	

^Screening values for radon dissolved in water has been defined as recreational water bodies in an open environment. In a closed environment or with poor ventilation, radon gas may build-up in that environment (Adelikhah, Shahrokhi, Chalupnik, Tóth-Bodrogi, & Kovács, 2020). An assessment of exposure to radon under these conditions should include a measurement of the air concentration to account for this radon build-up.

Table 5 - Scenario Specific (Generic Gross Alpha and Beta) Screening Values

Scenario	Alpha (Bq/L)	Beta (Bq/L)
Swimming – nominal	30	6
Swimming - extensive	14	3
Fishing	2	26
Fishing and Seafood Consumption	0.5	0.2
Surfing	2	5
Diving	18	4
Sailing	13	90
Kayaking	3	22

Wading	1.4	1.3
Thermal Spring	130	
enHealth	29	6

*Consumption of seafood is out of scope for the NHMRC recreational water guidelines.

3.1.2 Radionuclide Specific Screening Values

If the generic scenario specific screening values are exceeded further analysis of the water body is required to measure radionuclide specific concentrations. The radionuclide specific concentrations can be compared with calculated radionuclide specific screening levels. Table 6 shows the radionuclide specific screening values that can be applied to any scenario. Table 7 extend on this by include the radionuclide screening values for each of the considered scenarios. Table 8 shows radionuclide screening values for scenarios that include an exposure pathway due to sediment.

Radionuclide specific screening levels are the concentration of that radionuclide at which the operational dose level would be exceeded. Therefore, it is possible that no singular radionuclide specific screening level is greater than its screening value but the operational dose value is still exceeded. To ensure the total exposure does not exceed the operational dose value a sum of ratios approach must be applied, which is shown in Equation 12.

It is not practicable for a screening assessment to analyse the comprehensive list of radionuclides provided below. The radionuclides to be considered and measurement techniques used should be determined in consultation with relevant jurisdictional bodies and measurement laboratories, considering which radionuclides are likely to be present and of concern in the water body and what analyse is achievable in acceptable frame, following a graded approach. It is recommended that a gamma analysis is undertaken to assess a suite of radionuclides, along with radionuclide specific measurements for Po-210 and Ra-226/228.

Table 6 – Radionuclide Specific Screening Values (All exposure scenarios) (Bq/L)

Alpha		Beta		Gamma	
Am-241		Ag-110m		Co-60	
Cf-252		Ca-45		Cr-51	
Cm-242		Ce-141		I-125	
Cm-243		Ce-144		Mn-54	
Cm-244		Cl-36		Se-75	
Np-237		Co-57		Sn-113	
Pu-238		Co-58		Sr-85	
Pu-239		Cs-134		Tc-99m	
Pu-242		Cs-137		Zn-65	
Po-210		Fe-55		Zn-65	
Ra-224		Fe-59			
Ra-226		Hg-203			

Th-228		I-129	
Th-230		I-131	
Th-232		Ir-192	
U-235		Na-22	
U-238		Nb-95	
		Pm-147	
		Pu-241	
		Ru-103	
		Ru-106	
		S-35	
		Sb-124	
		Sb-125	
		Sr-89	
		Sr-90	
		Tc-99	
		Tl-204	
		Zr-95	
		Pb-210	
		Ra-228	

Table 7 – Radionuclide and Scenario Specific Screening Values (Bq/L)

	Swimming	Fishing	Surfing	Diving	Sailing	Kayaking	Beach	enHealth	Seafood*
Alpha									
Am-241									
Cf-252									
Cm-242									
Cm-243									
Cm-244									
Np-237									
Pu-238									
Pu-239									
Pu-242									
Po-210									
Ra-224									

Ra-226									
Th-228									
Th-230									
Th-232									
U-235									
U-238									
Beta									
Ag-110m									
Ca-45									
Ce-141									
Ce-144									
Cl-36									
Co-57									
Co-58									
Cs-134									
Cs-137									
Fe-55									
Fe-59									
Hg-203									
I-129									
I-131									
Ir-192									
Na-22									
Nb-95									
Pm-147									
Pu-241									
Ru-103									
Ru-106									
S-35									
Sb-124									
Sb-125									
Sr-89									
Sr-90									

Tc-99									
Tl-204									
Zr-95									
Pb-210									
Ra-228									
Gamma									
Co-60									
Cr-51									
I-125									
Mn-54									
Se-75									
Sn-113									
Sr-85									
Tc-99m									
Zn-65									

*Consumption of seafood is out of scope for the NHMRC recreational water guidelines.

Table 8 – Sediment Radionuclide Specific Screening Values (Bq/kg)

Alpha		Beta		Gamma	
Am-241		Ag-110m		Co-60	
Cf-252		Ca-45		Cr-51	
Cm-242		Ce-141		I-125	
Cm-243		Ce-144		Mn-54	
Cm-244		Cl-36		Se-75	
Np-237		Co-57		Sn-113	
Pu-238		Co-58		Sr-85	
Pu-239		Cs-134		Tc-99m	
Pu-242		Cs-137		Zn-65	
Po-210		Fe-55		Zn-65	
Ra-224		Fe-59			
Ra-226		Hg-203			
Th-228		I-129			
Th-230		I-131			
Th-232		Ir-192			
U-235		Na-22			

U-238		Nb-95			
		Pm-147			
		Pu-241			
		Ru-103			
		Ru-106			
		S-35			
		Sb-124			
		Sb-125			
		Sr-89			
		Sr-90			
		Tc-99			
		Tl-204			
		Zr-95			
		Pb-210			
		Ra-228			

Sum of Ratios

The sum of ratios approach for radionuclide specific measurements is a method used to assess the overall radiological quality by considering the combined activity concentrations of multiple radionuclides. This approach involves calculating the ratio of the measured concentration of each radionuclide to the radionuclide specific screening values (Table 7). These individual ratios are summed to show the fraction of the screening values measured in the water body. This approach is grounded in the principle that even if individual radionuclides are present at levels below their respective limits, their combined effect could still pose a significant risk.

Equation 12

$$\sum_i \frac{C_{RN_i}}{RN_{SL_i}} \leq 1$$

Where C_{RN_i} is the concentration of the i^{th} radionuclide present and RN_{SL_i} is the screening level of the i^{th} radionuclide.

The following examples demonstrate how this approach is to be used.

Example 1 – Screening Level not exceeded

Unfiltered water samples were collected from a beach and all exposure scenarios were assessed. The activity concentrations in the water samples where 15 Bq/L of U-238 and 300 Bq/L of Cs-137.

The radionuclide specific screening values for all scenarios are 33 Bq/L and 822 Bq/L for U-238 and Cs-137, respectively (Table 7).

Therefore,

$$\sum_i \frac{C_{RN_i}}{RN_{SL_i}} = \frac{15}{33} + \frac{300}{822} = 0.8$$

Since the **sum of ratios is less than one**, the **screening level has not been exceeded**.

Example 2 – Screening Level exceeded

Unfiltered water samples were collected from a river where the only associated recreational activity is kayaking. 20 Bq/L of U-235, 150 Bq/L of Pb-210 and 1000 Bq/L of Co-60 were measured in the water.

The radionuclide specific screening values for kayaking are 60 Bq/L, 254 Bq/L, and 9670 Bq/L for U-235, Pb-210, and Co-60 respectively.

Therefore,

$$\sum_i \frac{C_{RN_i}}{RN_{SL_i}} = \frac{20}{60} + \frac{150}{254} + \frac{1000}{9670} = 1.03$$

Since the **sum of ratios is greater than one**, the **screening level has been exceeded**.

3.1.3 Undertaking a Site-Specific Dose Assessment

If measured radionuclide concentrations in the water body exceed the radionuclide specific screening levels, a site-specific dose assessment of the recreational water body is required. Details on what undertaking a site-specific dose assessment can involve are described in Section 4.4. The dose assessment can follow any methodology agreed upon by the relevant state or territory jurisdiction. The methods outlined in this report, IAEA SRS-19, and IAEA TECDOC-1759 provide guidance on undertaking the site-specific dose assessment.

4. Operational Process

A flowchart outlining the approach to demonstrating whether the radiological content of a recreational water body does not exceed the defined reference level is shown in Figure 1. The flowchart contains multiple exit points or 'exit ramps', at the first point in the process at which it can be demonstrated that the radiological content does not exceed the operational dose value the 'exit ramp' at that stage of the process should be taken. At this point no further radiological assessment of the water body will be required and the need to undertake monitoring of the water body can be reconsidered. The process is designed with multiple 'exit ramps' to minimise burden on the responsible party to undertake more detailed analysis when it may not be required. The first stage of the operational process is to determine whether the monitoring of a recreational water body is necessary.

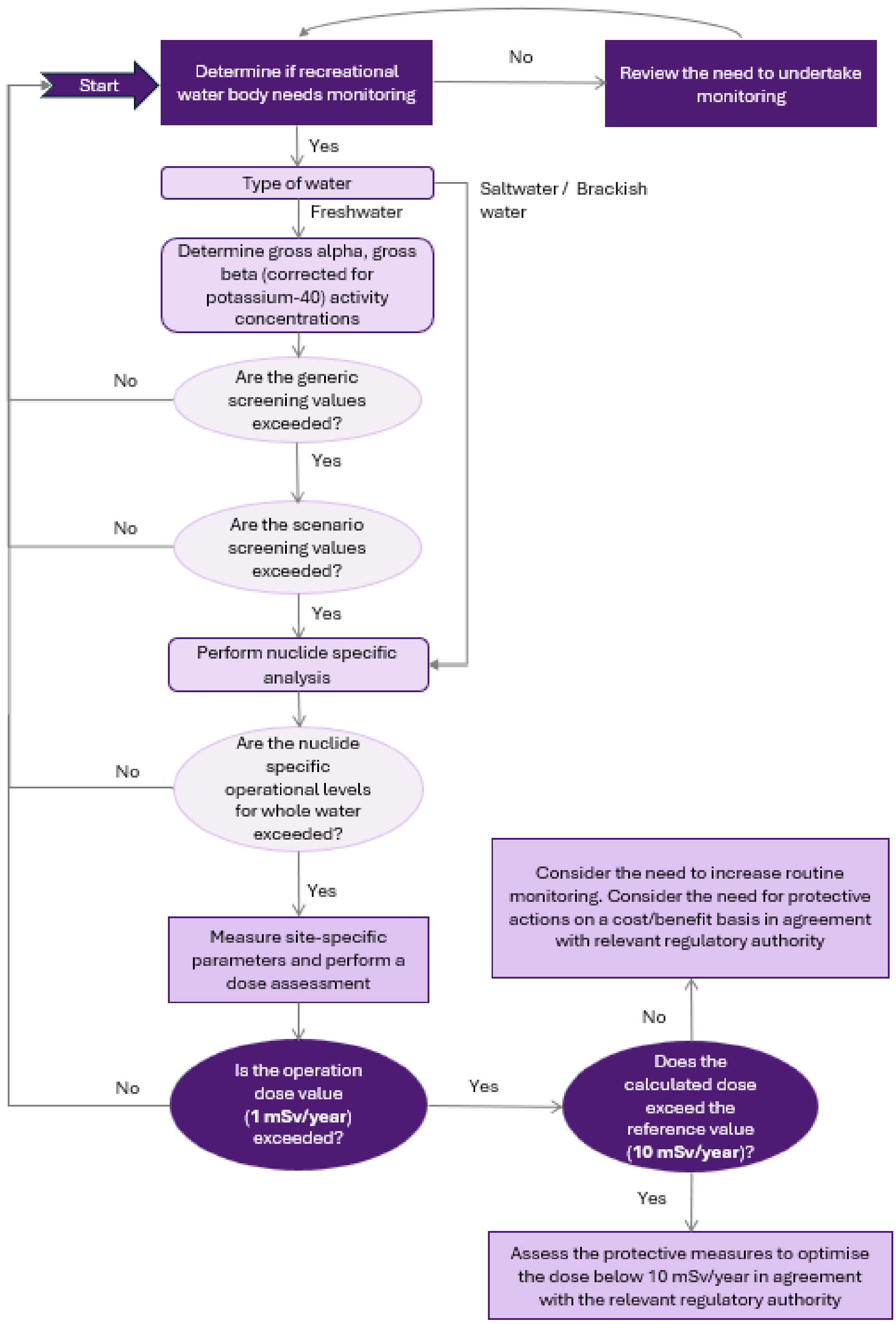

Figure 1 – Flowchart outlining the operational process for using recreational water radiological screening values

4.1 When to Monitor

Current evidence indicates that there are very few recreational water bodies that are likely to be contaminated by radionuclides at levels greater than those found naturally in the environment. Regular monitoring for radiological containments is not recommended for all recreational water bodies; however, monitoring of a recreational water may be undertaken based on the following factors:

- Areas which are known to have high naturally occurring concentrations of radioactive material (e.g. radionuclides of the thorium and uranium series in water sources). This includes groundwater resources and mineral and thermal springs.
- Proximity to legacy sites or areas where past activity may result in contaminated area, such as mineral sands mining.
- There is potential for future planned exposure situations to occur in the area, an assessment of the area can provide a baseline for the impact of future works.
- Providing public assurance if there is public concern about radiological impacts of a recreational water body.

If it is determined that the recreational water body should be assessed this does not mean that ongoing monitoring will be required, decisions on routine monitoring should also consider previous measurements.

4.1.1 Example 1 – Deciding not to monitor

Local authorities are investigating the water quality of a freshwater lake that is a popular swimming spot for locals. When determining if radiological contamination should be included in the investigation it was noted that there were no nearby legacy or mine sites, and the area was not known to have high levels of naturally occurring radioactive material.

In this case there are no identified radiological concerns in the water body and the surrounding area, it may therefore not be appropriate to undertake radiological monitoring of the water body as part of the water quality investigation.

4.1.2 Example 2 – Deciding to monitor

A river is a frequented recreation kayaking and fishing spot for many residents of nearby towns, upstream of a popular fishing area is nearby to a historic mineral sand mine and some resistants are concerned about potential contamination from the old mine running into the river.

Past mining activities in the area and public concern about the radiological impacts on the river are indicators that it would be beneficial to conduct radiological monitoring of recreationally occupied parts of the river.

4.2 Gross Alpha and Beta Analysis

Gross alpha and beta analysis is only practicable for freshwater bodies with total suspended solids (TSS) below 10 mg/L. For saltwater and brackish water samples gross alpha and beta analysis is not practical due to their high salt content, therefore radionuclide specific analysis is recommended for these samples (see section 4.3). Water samples are to be taken and analysed unfiltered to ensure the impact of suspended sediment on the effective dose is accounted for.

If possible, determining the gross alpha and beta concentration of water samples from the recreational water body should be the next stage in the operational process. Guidance on sampling and sample analysis can be found in (to be developed). **If the gross alpha and beta concentrations are below the generic screening values no further assessment is required** and the need to undertake monitoring can be reviewed**. If the generic screening values are exceeded the scenario specific screening values should be used**. A review of the common uses of the recreational water body should be undertaken and scenario specific screening values which reflect the use of the recreational water body identified (for example selecting the swimming and kayaking screening values for the assessment of a lake where other recreational activities do not occur). **If the gross alpha and beta concentrations are below the scenario specific screening values no further assessment is required** and the need to undertake monitoring can be reviewed.

If the scenario specific screening values are exceeded further analysis of water samples is required to determine specific radionuclide concentrations.

4.2.1 Example 3 – Generic Screening Levels are exceeded

A recreational water body is in an area historically used for uranium mining. A local assessment confirmed the water body is regularly used by a holiday park. The water body is known to the local authorities and is regularly monitored. Unfiltered water samples were collected from the water body. Total suspended solids were below 10 mg/L. Water samples were analysed for gross alpha and gross beta. The activity concentrations were 5 Bq/L gross alpha and 2.5 Bq/L gross beta.

Step 1: The activity concentrations should be compared with the generic screening values below.

	Gross Alpha (Bq/L)	Gross Beta (Bq/L)
Unfiltered water samples	5	2.5
Generic Screening levels	2	3

The activity concentrations exceeded the generic screening values.

Step 2: Activity concentrations should be compared to the scenario-specific screening levels shown below for each of the relevant recreational water activities of the river.

In this case, the most restrictive exposure scenario (i.e. highest potential exposure to radionuclides for a recreational water user) is swimming.

The activity concentrations should be compared with the scenario-specific screening values for swimming.

	Gross Alpha (Bq/L)	Gross Beta (Bq/L)
Unfiltered water samples	5	2.5
Swimming Screening levels	14	3

The activity concentrations did not exceed the scenario-specific screening levels for swimming.

Recommended action:

Since the concentrations were above both the generic but did not exceed the scenario-specific screening values, continue recreational use and assess the need for routine monitoring, ensuring ongoing safety and compliance.

Operational Guidance

If generic screening levels have been exceeded, but the scenario-specific screening values have not been exceeded, continue recreational use

4.2.2 Example 4 – Special Case: Thermal Springs in Closed Environment

A natural thermal spring, which has been partially enclosed in by a man-made structure, is a popular bathing area for tourist and locals. An initial analysis found that the gross alpha and beta concentrations in the thermal spring were below the generic screening criteria. However, as the springs were identified as a closed environment in an area where high levels of radon are likely to be present it was recommended that the air concentration of radon around the thermal spring be assessed.

The air concentration of radon near the thermal spring was found to be an average of 300 Bq/m^3, exceeding the screening value for air concentration of radon (250 Bq/m^3). The higher concentration of radon in the air than the thermal spring was partially ascribed to the build-up of radon due lack of ventilation around the thermal spring.

Operational Guidance

Exceeding the screening level for the air concentration of radon should trigger a more detailed assessment of the thermal springs use by the public to determine if a representative person visiting the thermal spring will receive an effective dose that exceeds the operational dose value and/or the reference level. If this the case mitigation measures should be considered, such as, ventilation measures and limiting the allowable time spent at the thermal springs.

4.3 Radionuclide Specific Analysis

Radionuclide specific analysis of water samples should be undertaken if the generic and scenario specific screening values have been exceeded or if the TSS of the water body is too high to undertake gross alpha and beta analysis. Guidance on sampling and sample analysis can be found in (to be developed), for both gross alpha and beta, and specific alpha, beta and gamma emitting radionuclides.

The sum of ratios approach, discussed in section 3.1.2, should be applied for radionuclide specific screening values. **If the sum of ratios for generic radionuclide specific screening values or scenario specific**

radionuclide specific screening values is below 1 then no further assessment is required. If the radionuclide specific screening values have been exceeded, then a more in-depth radiological assessment of the recreational water body is required.

4.3.1 Example 5 – Scenario Specific Screening Values are exceeded

A local assessment of a lake, which is popular swimming spot for locals, confirmed the presence of several naturally occurring radioactive materials. The lake receives water input from an area historically used for uranium mining. Initial measurements of the water were analysed for gross alpha and gross beta. The activity concentrations were 5 Bq/L and 4 Bq/L for gross alpha and beta, respectively. The gross beta concentration measured exceeds the swimming scenario screening values.

Step 1: As the generic and scenario specific screening values have been exceeded, further analysis of the water samples is required to determine the radionuclide specific concentrations in the lake. Recommended techniques for radionuclide specific water sample analysis are given in Annex 1.

Step 2: Activity concentrations should be compared to the swimming radionuclide-specific screening levels shown below for each of the relevant radionuclides analysed.

	U-238	Pb-210
Unfiltered water samples	5	4
Swimming Radionuclide Specific Screening levels	148	5

Using the sum of ratios approach the fraction of the screening levels measured is given below.

$$\sum_i \frac{C_{RN_i}}{RN_{SL_i}} = \frac{5}{148} + \frac{4}{5} = 0.83$$

Since the sum of ratios is less than 1, the activity concentrations have not exceeded radionuclide-specific screening levels for swimming.

Recommended action:

Since the concentrations were above both the generic and scenario-specific generic screening values, but the radionuclide-specific screening levels for swimming have not been exceeded continue recreational use with routine monitoring maintained, ensuring ongoing safety and compliance.

Operational Guidance

If generic screening levels have been exceeded, continue recreational use with routine monitoring maintained

4.3.2 Example 6 – Fishing when considering seafood ingestion as an exposure pathway (Seafood screening levels)

A river is a popular fishing spot with many locals frequently consuming seafood they caught in the river. There has recently been some concern about elevated levels of naturally occurring radioactive material in the area. An initial assessment of the river found that the gross alpha and beta concentrations in the water (freshwater; no total suspended solids) were 0.6 Bq/L and 0.3 Bq/L, respectively.

Seafood ingestion is the major exposure pathway to adults in this case study and cannot be considered out of scope and the ingestion of seafood generic screening values for an Adult should be applied.

Step 1: The activity concentrations should be compared with the seafood screening levels (detailed in Technical Report). These are 0.5 Bq/L and 0.2 Bq/L for gross alpha and beta, respectively.

The activity concentrations exceeded the seafood screening levels.

Step 2: Water samples are re-analysed or new water samples are collected for radionuclide-specific concentrations and compared to radionuclide specific screening values for seafood ingestion.

Water sample analysis found the river contained 0.3 Bq/L of Po-210, 0.3 Bq/L of U-238, 0.2 Bq/L of Cs-137, and 0.1 Bq/L of Ra-228.

Step 3: Following the tiered approach, the sum of ratios approach must be used to assess the overall radiological quality.

$$\sum_i \frac{C_{RN_i}}{RN_{SL_i}} = \frac{0.3}{1.95} + \frac{0.3}{10.83} + \frac{0.2}{13.90} + \frac{0.1}{0.26} = 0.64$$

The sum of the ratio of the concentration of each radionuclide compared to the ingestion of seafood screening value for that nuclide was 0.64.

Therefore, the **radionuclide specific screening values have not been exceeded.**

Operational Guidance

If seafood radionuclide specific screening levels have not been exceeded, continue recreational fishing

4.4 Site-specific Radiological Assessment

If all screening values have been exceeded a site-specific radiological assessment of the recreational water body should be conducted. A more detailed assessment can involve collecting a wider range of sample types (such as sediment on the shore) and/or collecting site-specific information, such as:

- Sediment distribution coefficients (K_d)
- The suspended sediment factor
- Specific habit data of a representative person

The site-specific radiological assessment should provide a conservative but reasonable estimate of the annual dose to a representative person using the recreational water body recreationally. **If the assessment demonstrates that the calculated dose is below the operational dose value of 1 mSv a year, then no further measures are required** and the need to continue monitoring the area can be considered.

If the operational dose (1 mSv/year) has been exceeded but the calculated dose is below the reference level of 10 mSv per year, then the need to increase the frequency of monitoring should be considered in agreement with the relevant health authorities or state regulators. Possible protective measures (e.g. remedial/protective actions) should be assessed, taking the benefit to cost (financial or societal) of any measures.

If the calculated dose exceeds the reference level (10 mSv/year) then intervention is expected. Possible protective measures should be assessed and appropriate remedial/protective measures implemented in consultation with relevant health authorities or state regulators.

A case study on site-specific radiological assessment is outlined in Appendix 3:

Appendix 1: List of Radionuclides Considered

Table 9 – Alpha Emitting Radionuclides

Artificial Radionuclides			Natural Radionuclides		
Am-241	Cm-243	Pu-238	Po-210	Th-228	U-235
Cf-252	Cm-244	Pu-239	Ra-224	Th-230	U-238
Cm-242	Np-237	Pu-242	Ra-226	Th-232	

Table 10 – Beta Emitting Radionuclides

Artificial Radionuclides						Natural Radionuclides
Ag-110m	Co-57	Fe-59	Ir-192	Ru-103	Sr-89	Pb-210
Ca-45	Co-58	H-3	Na-22	Ru-106	Sr-90	Ra-228
Ce-141	Cs-134	Hg-203	Nb-95	S-35	Tc-99	
Ce-144	Cs-137	I-129	Pm-147	Sb-124	Tl-204	
Cl-36	Fe-55	I-131	Pu-241	Sb-125	Zr-95	

Table 11 – Gamma Emitting Radionuclides

Artificial Radionuclides				
Co-60	I-125	Se-75	Sr-85	Zn-65
Cr-51	Mn-54	Sn-113	Tc-99m	

Appendix 2: List of Parameters Used

Table 12 – List of parameters used in effective dose calculations

Parameter	Symbol	Value
Concentration of radionuclide *r* in water (Bq/L)	$C_w(r)$	-
Concentration of radionuclide *r* in sediment (Bq/kg)	$C_c(r)$	-
Annual exposure time (h/y)	t	Table 14 – Annual exposure times for recreational water scenariosTable 14
Immersion in water factor	f_m	Table 15
Inadvertent ingestion of water (L/h)	H_w	Table 13
Inhalation rate (m^3/h)	R_S	Table 16
Air concentration of seaspray (kg/m^3)	C_s	0.01 (IAEA, 2015)

Density of seawater (kg/m³)	ρ_w	1000
Ratio of the concentrations of radon in water and air	r_{w-a}	10^{-4} (UNSCEAR, 2000)
Sediment distribution coefficient in water (L/kg)	K_d	IAEA TRS 422 (IAEA, 2004)
Density of coastal sediment (kg/m³)	ρ_s	1500 (TEPCO, 2022)
Thickness of coastal sediment (m)	d_s	0.1 (IAEA, 2015)
Suspended sediment concentration (kg/m³)	S	10^{-5} (IAEA, 2015)
Inadvertent sand ingestion rate (kg/h)	H_s	Table 17
Thickness of the sediment layer (m)	L_b	0.01 (IAEA, 2015)
Fraction of suspended particles in the water present in the coastal sediment	x	(IAEA, 2015)
Annual seafood ingestion (kg/y)	N	Table 18
Effective dose conversion factor from gamma radiation from the radionuclide from water immersion (mSv/h)/(Bq/L)	DC_m	ICRP 144 (ICRP, 2020)
Committed effective dose factor from ingestion of a radionuclide (mSv/Bq)	DC_g	ICRP 119 (ICRP, 2012)
Committed effective dose factor from inhalation of a nuclide (mSv/Bq)	DC_h	ICRP 119 (ICRP, 2012)
Effective dose per exposure of Radon-222 gas and progeny indoors (mSv/Bq)/(h/L)	DC_r	1.3 x 10^{-2} (ICRP, 2017)
Effective dose conversion factor from gamma radiation from a nuclide from sediment (mSv/h)/(Bq/m²)	DC_e	ICRP 144 (ICRP, 2020)
Concentration factor for marine biota (fish or crustaceans) in L/kg	DC_f	IAEA TRS 422 (IAEA, 2004)

Table 13 – Inadvertent Ingestion of Water rates for different recreational water activities

Recreational Water Activity	Inadvertent Ingestion Rate (L/hour)
Swimming	0.25 (DeFlorio-Barker, et al., 2018)
Wading	0.25 (DeFlorio-Barker, et al., 2018)
Surfing	0.17 (L/event) (Stone, Harding, Hope, & Slaughter-Mason, 2008)
Diving	0.2 (L/event) (Schijven & de Roda Husman, 2006)
enHealth	0.25 (L/event) (WHO, 2021)
Kayaking	0.02 (Dorevitch, et al., 2011)
Sailing	0.02 (Dorevitch, et al., 2011)

Table 14 – Annual exposure times for recreational water scenarios

Recreational Water Activity	Annual Exposure Time (h/y)
Swimming - nominal	150 (enHealth, 2012)
Swimming - extensive	312 (AUSPLAY, 2023a)
Fishing	720 (Pita, et al., 2022)
Surfing	520 (AUSPLAY, 2023b)
Diving	320 (Schijven & de Roda Husman, 2006)
Sailing	100 (Taverner Research Group, 2023)
Kayaking	400 (AUSPLAY, 2023c)
Wading	150 (enHealth, 2012)
Beach	365 (AUSPLAY, 2023d)
Thermal Spring	300 (enHealth, 2012)
enHealth	150 events/year (enHealth, 2012)

Table 15 – Immersion in water factors for recreational water scenarios

Recreational Water Activity	Immersion Factor
Swimming	1
Wading	1
Surfing	0.5
Diving	1
Sailing	0.5
Kayaking	0.5

Table 16 – Inhalation Rates

Age Group	Inhalation Rate for Light Exercise (ICRP pub 71 (ICRP, 1995)) (m^3/h)
Infant	0.19
1 year old	0.35
5 year old	0.57
10 year old	1.12
15 year old	1.38
Adult	1.5

Table 17 – Sand ingestion rates

Age Group	Sand Ingestion Rate (kg/h) (IAEA, 2015)
< 5-year-old	5×10^{-5}
≥ 5-year-old	5×10^{-6}

Table 18 – Annual Seafood Ingestion (IAEA, 2015)

Age Group	Annual fish ingestion (kg/a)	Annual Crustacean and Mollusc Ingestion (kg/a)
Adult	50	15

Appendix 3: Case Study - Site-specific Dose Assessment

An estuary in a national park is a popular recreational spot for locals and tourists. Recently there has been some concern among the public about contamination in the estuary due to historical mineral sands mining that occurred several kilometres upstream from the main recreational area. Local authorities are aware, and an initial investigation has been conducted to identify what steps should be taken to ensure the estuary is safe for recreational use.

Initial Assessment

The initial assessment follows the operational process shown in the flowchart (Figure 1). The first step considered by local authorities is whether radiological monitoring of the estuary is necessary. Considering the historical mineral sands mining activity nearby, public concern, and recreational popularity of the site; local authorities in consultation with their jurisdictional regulator have decided to undertake an initial radiological assessment of the estuary.

The estuary consists of brackish water and has high salinity, therefore gross alpha and beta analysis of the water is impractical. The generic screening level components of the operational process are bypassed, and water samples are analysed for specific radionuclide concentrations.

Three radionuclides were identified:

- 5 Bq/L of U-238
- 4 Bq/L of Ra-226
- 1 Bq/L of Pb-210

The measured radionuclide concentrations were compared to the radionuclide specific screening values for generic for kayaking, swimming, and beach scenarios is shown in Table 19.

Table 19 – Initial measured activity of water samples collected from the estuary compared with radionuclide specific screening values

Radionuclide	Measured activity (Bq/L)	Screening Values (Bq/L)		
		Swimming	Kayaking	Beach
U-238	6	158	21.0	461
Ra-226	4	15.8	37.8	28.9

Ra-228	2	3.2	23.0	4.9

The sum of the ratios of measured radionuclide activity concentrations to the most conservative scenario specific screening level is shown below (using Equation 12).

$$\sum_i \frac{C_{RN_i}}{RN_{SL_i}} = \frac{6}{21} + \frac{4}{15.8} + \frac{2}{3.2} = 1.2$$

As the sum of ratios is greater than one, the radionuclide specific screening values have been exceeded, and a site-specific radiological assessment is undertaken.

Site-Specific Assessment

As a result of the exceedance of the radionuclide screening values along with the public concern about the impacts of historical mining on the estuary, local authorities in consultation with their relevant regulator have decided to conduct a site-specific assessment.

Site-specific parameters

The first stage of this assessment was collecting site-specific data on the estuary's occupancy by members of the public and recreational activities.

To determine the occupancy levels for recreational activities undertaken at the estuary, a survey of visitors (i.e. recreational water users) to the estuary was conducted during the summer period. For children and infants present at the estuary, the parents or guardians were asked to complete the survey on behalf of them. The survey included the following:

- What is your postcode? (To distinguish local recreators from tourists)
- What is your age range? (0-1 years, 1-5 years, 5-10 years, 10-15 years, >15 years)
- How many days a year do you visit?
- How do you spend your time when visiting and how long do you spend on each activity?

Based on the survey results it was determined the recreational activities undertaken at the estuary were:

- Swimming
- Stand-up paddle boarding
- Kayaking
- Playing/relaxing in the beach sand

Two representative groups were determined based on conservative occupancy times and activities from the survey, a representative tourist and a representative local.

The representative tourist spent 3 days a year at the estuary for 7 hours a day. Tourist age groups included 5-10 years and >15 years. The representative tourist spends 2 hours a day swimming, 2 hours a day kayaking, 2 hours a day on the beach sand, and 1 hour a day stand-up paddle boarding.

The representative local visited the estuary once a week throughout the year for an average of 2 hours. The type of activities undertaken varied for each age group with a conservative breakdown of time spent for each age group is shown in Table 20.

Table 20 – Estuary site-specific dose assessment representative local time spent per visit

Age Group	Time spent per activity
0-1 years	Beach – 2 hours
1-5 years	Swimming – 1 hour, Beach – 1 hour
5-10 years	Swimming – 2 hours
10-15 years	Swimming – 1 hour, Kayaking – 1 hour
>15 years	Swimming – 1 hour, Kayaking – 1 hour

The time spent on the shore of the estuary (beach) was the main activity at the estuary for both the representative tourist and local. It was determined sediment samples along the beach shore should be collected and analysed for radionuclide activity concentration. The site-specific parameters obtained from sediment samples for the site-specific dose assessment are the density of the sediment and the effective thickness of the sediment, which were measured to be 1200 kg/m^3 and 0.08 m respectively.

It was decided generic values would be used for all other parameters rather than undertake additional measurements on a cost-benefit basis (e.g. the density of sea spray was designated the IAEA TECDOC-1759 value of 0.01 kg/m^3).

Sampling and Analysis

Unfiltered water samples were appropriately collected from locations within the recreational area of the estuary and sediment samples were collected from along the estuary shoreline. The samples were analysed for radionuclide specific activity concentrations, which are shown in Table 21.

Table 21 – Measured radionuclide specific concentrations in water and sediment for estuary site-specific assessment

Water Samples		Sediment Samples	
Radionuclides Identified	Activity Concentration (Bq/L)	Radionuclides Identified	Activity Concentration (Bq/kg)
U-238	6	**U-238**	100
Ra-226	4	**Pb-210**	150
Ra-228	2		

Identification of Exposure Pathways

The exposure pathways for swimming, kayaking, and relaxing/playing on the beach have been previously identified in this document and are shown in Table 3. However, the exposure pathways for stand-up paddle boarding are not included and must be identified.

Stand-up paddling boarding involves standing on a paddle board, typically holding a single paddle, used to move the board over a water body. As the recreational activity involves moving over the water surface, external exposure from the water surface should be considered, using the external dose from immersion in water (Equation 2) with dose reduction factor of 0.5 (U.S. EPA, 2019). Inadvertent ingestion of water may occur due to splashing of water during paddling, an inadvertent ingestion of water rate of 0.015 L per hour during limited contact recreational activities on surface waters is recommended (Dorevitch, et al., 2011). The final exposure pathway identified is inhalation of seaspray as the activity occurs above water at the intersection between a river and the ocean.

Effective Dose Calculation

The effective dose calculations for the identified exposure pathways and required parameters are shown in Table 22, Table 23, Table 24, and Table 25.

Table 22 – Annual effective dose calculations for exposure pathways identified for the estuary site-specific assessment (IAEA, 2015)

Exposure Pathway	Annual Effective Dose Calculation (mSv/y)
Immersion in water	$E_m = t\, f_m \sum_r C_w(r) DC_m(r)$ (Equation 2)
Inadvertent ingestion of water	$E_g = t\, H_w \sum_r C_w(r)\, DC_g(r)$ (Equation 3)
Inhalation of sea-spray	$E_h = t\, R_S \left(\frac{C_s}{\rho_w}\right) \sum_r C_w(r)\, DC_h(r)$ (Equation 4)
External doses from beach sand	$E_e = t\, \rho_s\, d_s \sum_r C_b(r)\, DC_e(r)$
Inadvertent ingestion of beach sand	$E_s = t\, H_s \sum_r C_b(r)\, DC_g(r)$

Table 23 – Parameters used for effective dose calculation for estuary site-specific assessment

Parameter	Symbol	Value
Annual exposure time (h/y)	t	Table 24
Immersion in water factor	f_m	Table 15, Stand-up paddle boarding: 0.5
Inadvertent ingestion of water (L/h)	H_w	Table 13, Stand-up paddle boarding: 0.015
Inhalation rate (m^3/h)	R_S	Table 16
Air concentration of seaspray (kg/m^3)	C_s	0.01 (IAEA, 2015)
Density of seawater (kg/m^3)	ρ_w	1000
Thickness of coastal sediment (m)	d_s	0.1 (IAEA, 2015)
Inadvertent sand ingestion rate (kg/h)	H_s	Table 17
Concentration of radionuclide *r* in water (Bq/L)	$C_w(r)$	Table 21
Concentration of radionuclide *r* in sand (Bq/kg)	$C_b(r)$	Table 21

Table 24 – Annual exposure times per activity for representative groups

Representative Person	Annual Exposure time per Activity (t) (h/y)			
	Swimming	Kayaking	Stand-up paddle boarding	Beach
Tourist	6	6	6	3
Local (0-1 years)	0	0	0	104
Local (1-5 years)	52	0	0	52
Local (5-10 years)	104	0	0	0

Local (10-15 years)	52	52	0	0
Local (>15 years)	52	52	0	0

Table 25 – Dose conversion coefficients for immersion in water for identified radionuclides in estuary site-specific assessment

Radionuclide	Infant	1 year	5 years	10 years	15 years	Adult
DC_m – Immersion in Water (mSv/h)/(Bq/L) (ICRP, 2020)						
U-238	5.89E-11	4.72E-11	4.26E-11	3.85E-11	2.91E-11	2.67E-11
Ra-226	3.23E-9	2.95E-9	2.73E-9	2.44E-9	2.28E-9	2.14E-9
DC_g – Ingestion (mSv/Bq) (ICRP, 2012)						
U-238	3.4E-4	1.2E-4	8E-5	6.8E-5	6.7E-5	4.5E-5
Ra-226	4.7E-3	9.6E-4	6.2E-4	8E-4	1.5E-3	2.8E-4
Ra-228	3E-2	5.7E-3	3.4E-3	3.9E-3	5.3E-3	6.9E-4
Pb-210	8.4E-3	3.6E-3	2.2E-3	1.9E-3	1.9E-3	6.9E-4
DC_h - Inhalation (mSv/Bq) (ICRP, 2012)						
U-238	2.9E-2	2.5E-2	1.6E-2	1E-2	8.7E-3	8E-3
Ra-226	1.5E-2	1.1E-2	7E-3	4.9E-3	4.5E-3	3.5E-3
Ra-228	1.5E-2	1E-2	6.3E-3	4.6E-3	4.4E-3	2.2E-3
DC_e – Ambient Dose from Soil (mSv/h)/(Bq/m^2) (ICRP, 2020)						
U-238	5.8E-13	3.58E-13	2.82E-13	2.26E-13	1.86E-13	1.72E-13
Pb-210	6.21E-12	5.06E-12	4.38E-12	3.55E-12	3.12E-12	2.78E-12

The total annual effective dose to a representative person is the sum of the calculated effective dose for all exposure activities and exposure pathways for each activity. An example of this calculation for the adult tourist is shown below.

$$\begin{aligned} E_{tourist_{adult}} &= \sum_{activity} \sum_{pathway} E_{activity,\ pathway} \\ &= \sum_{path} E_{swimming}(path) + \sum_{path} E_{kayaking}(path) \\ &+ \sum_{path} E_{stand-up\ paddle\ boarding}(path) + \sum_{path} E_{beach}(path) \end{aligned}$$

Effective doses from each exposure activity are shown below.

$$E_{swimming} = \sum exposure\ pathways = E_{immersion} + E_{inadvertent\ ingestion}$$
$$= t\ f_m \sum_r C_w(r) DC_m(r) + t\ H_w \sum_r C_w(r) DC_g(r)$$
$$= t\ f_m \left(C_w(U238) \times DC_m(U238) + C_w(Ra226) \times DC_m(Ra226)\right)$$
$$+ t\ H_w \left(C_w(U238) \times DC_g(U238) + C_w(Ra226) \times DC_g(Ra226)\right.$$
$$\left.+ C_w(Ra228) \times DC_g(Ra228)\right)$$
$$= 6\ (\frac{h}{y}) \times 1 \times (6 \left(\frac{Bq}{L}\right) \times 2.67 \times 10^{-11}\ (\frac{mSv}{h} / \frac{Bq}{L})$$
$$+ 4\ (\frac{Bq}{L}) \times 2.14 \times 10^{-9}\ (\frac{mSv}{h} / \frac{Bq}{L}))$$
$$+ 6\ (\frac{h}{y}) \times 0.25\ (\frac{L}{h}) \times (6 \left(\frac{Bq}{L}\right) \times 4.5 \times 10^{-5} \left(\frac{mSv}{Bq}\right) + 4 \left(\frac{Bq}{L}\right) \times 2.8 \times 10^{-4} \left(\frac{mSv}{Bq}\right)$$
$$+ 2 \left(\frac{Bq}{L}\right) \times 6.9 \times 10^{-4} \left(\frac{mSv}{Bq}\right)) = 0.004\ mSv/y$$

$$E_{kayaking} = \sum exposure\ pathways = E_{immersion} + E_{inadvertent\ ingestion} + E_{inhalation}$$
$$= t\ f_m \sum_r C_w(r) DC_m(r) + t\ H_w \sum_r C_w(r) DC_g(r) + t\ R_S \left(\frac{C_s}{\rho_w}\right) \sum_r C_w(r)\ DC_h(r)$$
$$= 6\ (\frac{h}{y}) \times 0.5 \times (6 \left(\frac{Bq}{L}\right) \times 2.67 \times 10^{-11}\ (\frac{mSv}{h} / \frac{Bq}{L})$$
$$+ 4\ (\frac{Bq}{L}) \times 2.14 \times 10^{-9}\ (\frac{mSv}{h} / \frac{Bq}{L}))$$
$$+ 6\ (\frac{h}{y}) \times 0.015\ (\frac{L}{h}) \times (6 \left(\frac{Bq}{L}\right) \times 4.5 \times 10^{-5} \left(\frac{mSv}{Bq}\right) + 4 \left(\frac{Bq}{L}\right) \times 2.8 \times 10^{-4} \left(\frac{mSv}{Bq}\right)$$
$$+ 2 \left(\frac{Bq}{L}\right) \times 6.9 \times 10^{-4} \left(\frac{mSv}{Bq}\right))$$
$$+ 6\ (\frac{h}{y}) \times 1500\ (\frac{L}{h}) \times \frac{0.01 \left(\frac{kg}{m^3}\right)}{1000 \left(\frac{kg}{m^3}\right)} \times (6 \left(\frac{Bq}{L}\right) \times 8 \times 10^{-3} \left(\frac{mSv}{Bq}\right)$$
$$+ 4 \left(\frac{Bq}{L}\right) \times 3.5 \times 10^{-3} \left(\frac{mSv}{Bq}\right) + 2 \left(\frac{Bq}{L}\right) \times 2.2 \times 10^{-3} \left(\frac{mSv}{Bq}\right)) = 0.006\ mSv/y$$

$$E_{stand-up\ paddle\ boarding} = \sum exposure\ pathways = E_{immersion} + E_{inadvertent\ ingestion} + E_{inhalation}$$

$$= t\ f_m \sum_r C_w(r) DC_m(r) + t\ H_w \sum_r C_w(r) DC_g(r) + t\ R_S \left(\frac{C_s}{\rho_w}\right) \sum_r C_w(r)\ DC_h(r)$$

$$= 6\ (\frac{h}{y}) \times 0.5 \times (6 \left(\frac{Bq}{L}\right) \times 2.67 \times 10^{-11}\ (\frac{mSv}{h} / \frac{Bq}{L})$$

$$+ 4\ (\frac{Bq}{L}) \times 2.14 \times 10^{-9}\ (\frac{mSv}{h} / \frac{Bq}{L}))$$

$$+ 6\ (\frac{h}{y}) \times 0.015\ (\frac{L}{h}) \times (6 \left(\frac{Bq}{L}\right) \times 4.5 \times 10^{-5} \left(\frac{mSv}{Bq}\right) + 4 \left(\frac{Bq}{L}\right) \times 2.8 \times 10^{-4} \left(\frac{mSv}{Bq}\right)$$

$$+ 2 \left(\frac{Bq}{L}\right) \times 6.9 \times 10^{-4} \left(\frac{mSv}{Bq}\right))$$

$$+ 6\ (\frac{h}{y}) \times 1500\ (\frac{L}{h}) \times \frac{0.01 \left(\frac{kg}{m^3}\right)}{1000 \left(\frac{kg}{m^3}\right)} \times (6 \left(\frac{Bq}{L}\right) \times 8 \times 10^{-3} \left(\frac{mSv}{Bq}\right)$$

$$+ 4 \left(\frac{Bq}{L}\right) \times 3.5 \times 10^{-3} \left(\frac{mSv}{Bq}\right) + 2 \left(\frac{Bq}{L}\right) \times 2.2 \times 10^{-3} \left(\frac{mSv}{Bq}\right)) = 0.006\ mSv/y$$

$$E_{beach} = \sum exposure\ pathways = E_{external} + E_{inadvertent\ ingestion\ of\ sediment}$$

$$= t\ \rho_s\ d_s \sum_r C_b(r)\ DC_e(r) + t\ H_s \sum_r C_b(r)\ DC_g(r)$$

$$= 3 \left(\frac{h}{y}\right) \times 1000 \left(\frac{kg}{m^3}\right) \times 0.1\ (m) \times (100\ (\frac{Bq}{kg}) \times 1.72 \times 10^{-13}\ ((\frac{mSv}{h})/(\frac{Bq}{m^2}))$$

$$+ 150\ (\frac{Bq}{kg}) \times 2.78 \times 10^{-12}\ ((\frac{mSv}{h})/(\frac{Bq}{m^2})))$$

$$+ 3 \left(\frac{h}{y}\right) \times 5 \times 10^{-6}\ (\frac{kg}{h}) \times (100 \left(\frac{Bq}{kg}\right) \times 4.5 \times 10^{-5} \left(\frac{mSv}{Bq}\right)$$

$$+ 150 \left(\frac{Bq}{kg}\right) \times 6.9 \times 10^{-4} \left(\frac{mSv}{Bq}\right)) = 2\ \mu Sv/y$$

Therefore, the exposure to the representative adult tourist is

$$E_{tourist_{adult}} = \sum_{activity} E_{activity} = E_{swimming} + E_{kayaking} + E_{stand-up\ paddiling\ boarding} + E_{beach}$$

$$= 0.004 + 0.006 + 0.006 + 0.000002 \approx 0.016\ mSv/year$$

Table 26 shows the calculated doses to all representative groups.

Table 26 – Calculated annual doses to the representative groups for the estuary site-specific assessment

Representative Group	Annual Dose (mSv/year)				
	Swimming	Kayaking	Stand-up paddle board	Beach	Total
Tourist					
5-year old	0.015	0.006	0.006	0.000005	0.027

10-year old	0.017	0.007	0.007	0.000005	0.031
Adult	0.004	0.006	0.006	0.000002	0.016
Local					
Infant	0	0	0	0.007	0.007
5-year old	0.127	0	0	0.0001	0.127
10-year old	0.300	0	0	0	0.300
15-year old	0.221	0.070	0	0	0.291
Adult	0.036	0.054	0	0	0.090

The highest calculated annual dose to a representative group was 0.3 mSv/year to a 10-year old local, which is below the operational dose value of 1 mSv/year. The site-specific assessment of the estuary shows that the calculated doses to a representative member of the public are below both the operational dose value and the reference level, therefore no protection or mitigation measures need to be considered. Site-specific screening values and/or ongoing monitoring of the estuary may be established to ensure radiological levels remain below the operational dose value and reference level.

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