Radiologisk konsekvensanalyse ved utslipp av radionuklider fra IFE

Assessment of dose rates to non-human biota - NUK

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Task Report

Version 3

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1 Introduction

The Institute for Energy Technology (IFE) is an independent research foundation, established by the government of Norway in 1948 [1]. When founded, IFE's main goal was nuclear research, but currently IFE is one of the leaders in petroleum, environmental and nuclear technology as well as energy research and safety.

IFE is organized in three divisions, each of them further divided into sectors and departments:

- Nuclear Technology (NUK)
- Radiopharmacy (Agilera Pharma As (Agilera))
- Research and Development (Forskning & Utvikling (FoU))

IFE is currently responsible for managing several nuclear facilities located in Norway (Kjeller and Halden sites). The facilities located in Kjeller are situated 3 km north-east of the town of Lillestrøm and around 20 km north-east of Oslo (Figure 1-1).

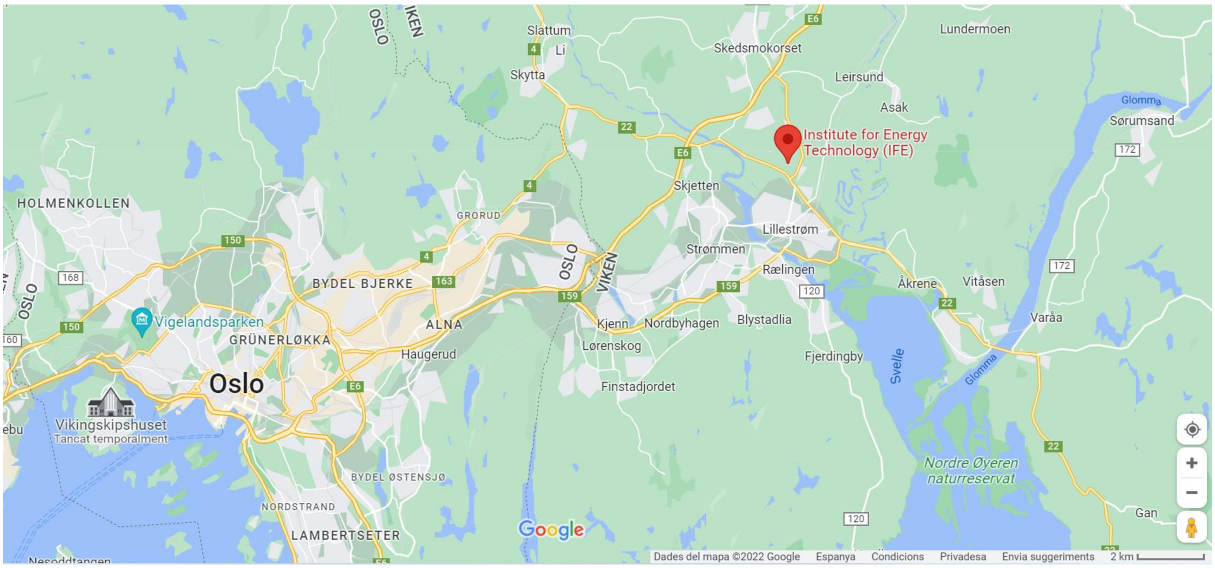


Figure 1-1: *Localization of IFE-Kjeller's site [2].*

IFE holds a permit for liquid and airborne discharges from the facilities, issued pursuant to the Act of 13 March 1981 No.6 Protection Concerning Against Pollution and Waste [3]. This permit allows for the receipt, treatment and intermediate storage of radioactive waste from the isotope production, research reactors and research activities, as well as radioactive waste from external users. Additionally, it provides authorization for radioactive discharges to air and water from the reactor operations, production of fuel, tracers and radiopharmaceuticals, investigations of irradiated fuel and treatment of radioactive waste at the company´s waste facility. IFE is obliged to reduce its emissions as far as possible without unreasonable costs even if all the discharges are kept within the emission limits.

The split of IFE into three independent divisions requires a new regulatory permit for liquid and airborne discharges to the environment during normal operations for each division. IFE has been required by the Norwegian Radiation and Nuclear Safety Authority (DSA) to perform a new environmental risk assessment including all relevant substances IFE has permission or requests permission to release. DSA has sent a series of letters to IFE where some requirements to be considered in the forthcoming environmental assessment are stated.

1.1 Objective

An environmental impact assessment of the future discharge of radioactive substances from IFE Kjeller plants both to human and non-human biota has been undertaken for each of the IFE's divisions following the same base conceptual model.

The project was divided into four tasks:

- Task 1: Preliminary model definition and parametrization
- Task 2: Impact assessment to the public
- Task 3: Impact assessment to non-human biota
- Task 4: Training on assessment approaches and tools to IFE

This report presents the work conducted in the frame of Task 3 – impact assessment to non-human biota for the NUK division of IFE. The report draws on information presented in the Task 2 report [4] on impact assessment to the public, which presents the radionuclide transport models from which environmental activity concentrations (air, soil, sediment and water) have been derived and used as input to the assessment of dose rates to non-human biota.

It is important to note that the science behind the assessment of biota dose rates is not sufficiently developed at the present time to be able to do dynamic assessments for short-term discharge variations within an operational assessment (i.e., where multiple different radionuclides and multiple different organisms are considered) or associated with an accident scenario. Assessment approaches, such as ERICA and its associated software tool, are based on instantaneous equilibrium factors or ratios, whether between activity in water and sediment (the partition coefficient, Kd) or in water / sediment / soil and the biota (the concentration ratio, CR). Assessment approaches therefore aim to determine dose rates over a 1-year integration period, based on annually averaged environmental activity concentration data. Benchmarks, thresholds and screening values are equally set for comparison to annually averaged values (i.e. chronic rather than acute exposure conditions).

Based on the reasons outlined above, this assessment is focused on annually averaged environmental concentrations derived from routine operational emissions.

1.2 Report structure

This report firstly sets out the assessment context and provides a brief overview on the environmental modelling undertaken in Task 2 [4] (see Section 2). An introduction to the Environmental Risk from Ionising Contaminants: Assessment and Management (ERICA) tool is then provided (Section 3). The site-specific application of the ERICA assessment tool is presented in Section 4. Results of the radiological assessment to non-human biota are then presented and discussed in Section 5. A summary is provided in Section 6 and references in Section 7. Parameter values associated with the reference organisms considered here are given in Appendix A. Assessment results for total dose rates, internal dose rates and external dose rates for all organisms and all radionuclides considered, for the 60th year of the assessment, are given in Appendix B.

2 Assessment context

The Task 2 report [4] details the environmental modelling and human dose assessment undertaken using the Ecolego model [5, 6] and supporting atmospheric dispersion modelling using AREMOD [7, 8]. Aspects of the environmental modelling that have formed the basis for this non-human biota dose assessment are summarized briefly in this section. Two main source terms are identified: (1) the emission of radioactive gases to the atmosphere and (2) the discharge of radionuclides in liquid form to the Nitelva River through the NALFA pipeline.

The assessment approach presented here capitalizes on the activity concentrations predicted in environmental media by the Ecolego model. This ensures that there is a consistent approach to modelling of radionuclide transport between human and non-human biota assessments, and consistent parameterization, where appropriate.

The work presented here is a prospective assessment, i.e., a predictive assessment of the effects of future discharges at their proposed limits. The presence of radioactivity in the environment from natural sources, previous discharges from IFE facilities, and fall-out from nuclear accidents and atmospheric tests is not considered.

2.1 Discharges to atmosphere

Air emissions include radionuclides emitted to the atmosphere in gas or aerosol form through chimneys and other such emission points located in different buildings on the IFE-Kjeller site. Each IFE's division has different emission points as shown in Figure 2-1.

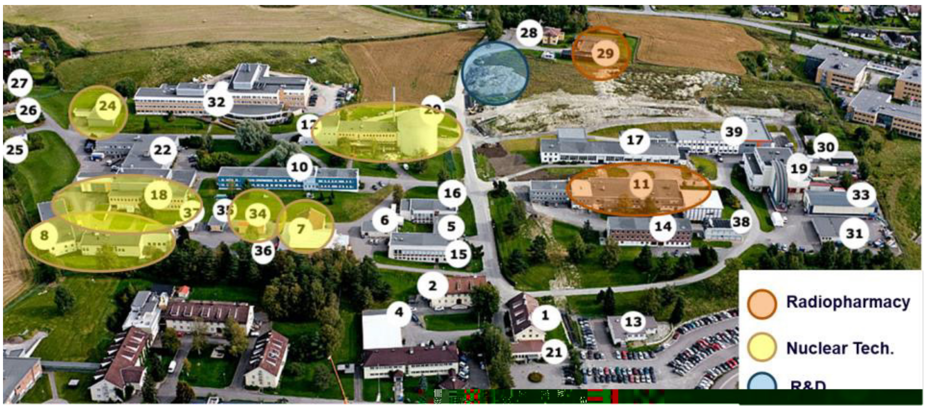


Figure 2-1. *Gas emission point locations per each division.*

The atmospheric model considers that radionuclides released to the atmosphere are dispersed to agriculture and residential areas located few hundred meters from IFE-Kjeller facilities (see selected area in Figure 2-2).

Figure 2-2. *Selected areas for the atmospheric model*

As shown in Figure 2-2, radionuclides are then deposited to the croplands area. The croplands are considered to consist of two layers: topsoil and deep soil between which radionuclides can be transferred via different mechanisms:

- Bioturbation, which refers to the physical, chemical, and biological alteration of soil layers by living organisms.
- Advection, which refers to the transport of radionuclides by the flow of water.
- Diffusion, which refers to the movement of radionuclides from high concentration regions to lower ones.

Besides the abovementioned processes, the model also considers the decay of radionuclides and the sorption of radionuclides into the soil.

The short-list of radionuclides selected for assessment in the Task 2 report [4] and the associated annual discharge limits used in the modelling of gaseous emissions are shown in Table 2-1.

Table 2-1. *Annual discharge emissions to atmosphere assessed*

Radionuclide	NUK (Bq/y)
Ac-227	1.0E+06
Br-82	1.0E+09
Cs-134	1.0E+07
Cs-135	1.0E+06
Cs-137	3.0E+07
Eu-152	5.0E+06
Eu-154	1.0E+07
Gd-153	1.0E+06
H-3	2.0E+12
Hg-203	1.0E+04
Ra-224	1.0E+06
Ra-228	1.0E+03
Rn-222	1.0E+09
Sr-90	3.0E+07
Tb-160	1.0E+06
Tb-161	1.0E+06
Tc-99	1.0E+06
Th-228	5.0E+05

** Any excess Ra-224 that is unsupported by the parent radionuclide Th-228 will decay rapidly and as such it has been assessed as being in equilibrium with the parent*

2.2 Discharges to water

The surface water model considers the transport of radionuclides released to the environment via liquid discharges to the Nitelva River. The model includes the river and agricultural areas situated closed to the river, from which extracts water is used for irrigating the croplands. The section of the river modelled, and the selected cropland areas are presented in Figure 2-3.

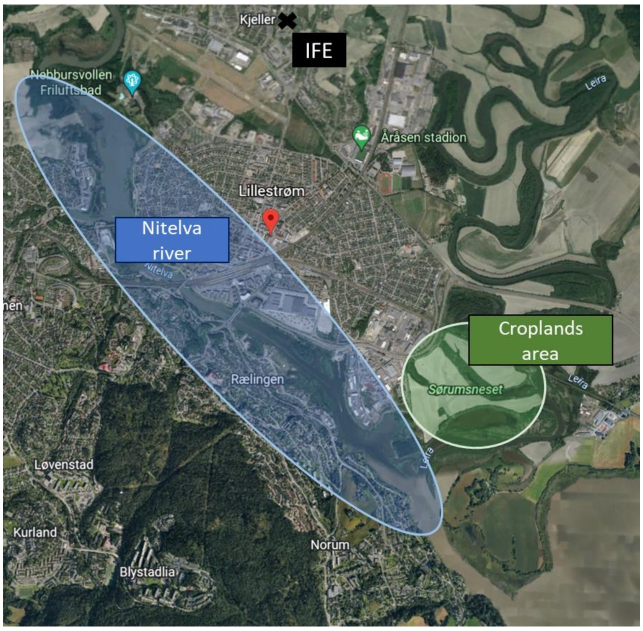


Figure 2-3. *Selected areas for the surface water model.*

The Nitelva River is divided into two compartments, this allows the model to investigate the decrease in radionuclide concentration in the areas further from the discharge point. A third river compartment, named “River downstream”, was added to account for the water flux leaving the studied system. The model considers the deposition of particulate matter on riverbed sediments, which are divided into two compartments: top and deep sediment, due to the differing properties of the layers. Radionuclides can be transported between the river and the sediment compartments via the following mechanisms:

- Advection, accounting for the waterflow between river compartments.
- Sedimentation, considering the deposition of matter on sediments.
- Resuspension, taking into account the removal of the deposited matter from sediments.
- Diffusion, considering the effects of diffusivity due to the water content.

Radionuclides released in liquid form originated in each division are discharged together from the IFE Building nº 8 via the NALFA pipeline to the Nitelva River (see Figure 2-4). The release occurs three times per year, and the Task 2 modelling assumes that 1/3 of the annual limit is released at every discharge during a period of 28.6 hours.

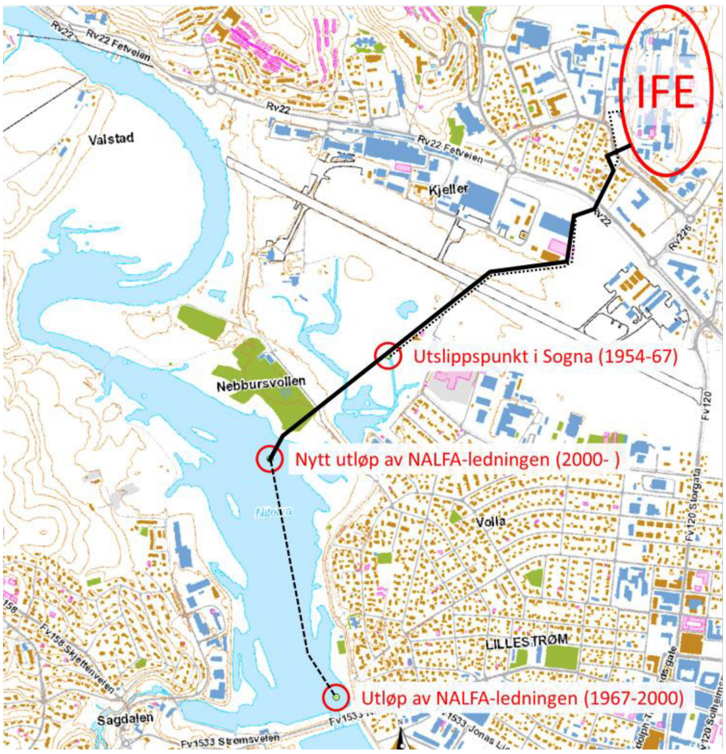


Figure 2-4. *Discharge pipeline from the IFE-Kjeller facilities*

The short-list of radionuclides selected for assessment in the Task 2 report [4] and the associated annual discharge limits used in the modelling of aqueous emissions are shown in Table 2-2.

Table 2-2. *Annual discharge emissions to river assessed*

Radionuclide	NUK (Bq/y)	Radionuclide	NUK (Bq/y)
H-3	5.0E+12	Cs-137	1.5E+08
Sc-46	1.0E+04	Lu-177	5.0E+08
Co-60	2.7E+08	Lu-177m	1.0E+04
Ru-106	1.0E+07	Ra-223	2.0E+08
Ag-108m	5.0E+06	Ra-224	1.0E+06
Cd-109	3.0E+07	Ra-228	1.0E+07
Ag-110m	1.0E+06	Th-232	1.0E+06
Sn-113	1.0E+06	Pu-239	1.5E+07
I-125	5.0E+07	Pu-240	1.5E+06
I-131	5.0E+08	Pu-242	1.0E+05
Cs-134	2.5E+07		

3 ERICA assessment model

The radiological assessment for non-human biota associated with aqueous and gaseous emissions of radioactivity from the Kjeller site, has been undertaken using the ERICA assessment methodology and associated tool (version 2.0 – build 2.0.185) [9].

ERICA was developed within a European Commission European Atomic Energy Community (EURATOM) funded project that ran from 2004 until its completion in 2007. The resultant assessment methodology and associated tool (see Figure 3-1) enable the impacts of radioactivity in the environment to be evaluated through the evaluation of absorbed dose rates to a set of reference organisms within a tiered approach. Whilst the ERICA project ended in 2007, the assessment tool has continued to be maintained by an ERICA Consortium, now led by DSA.

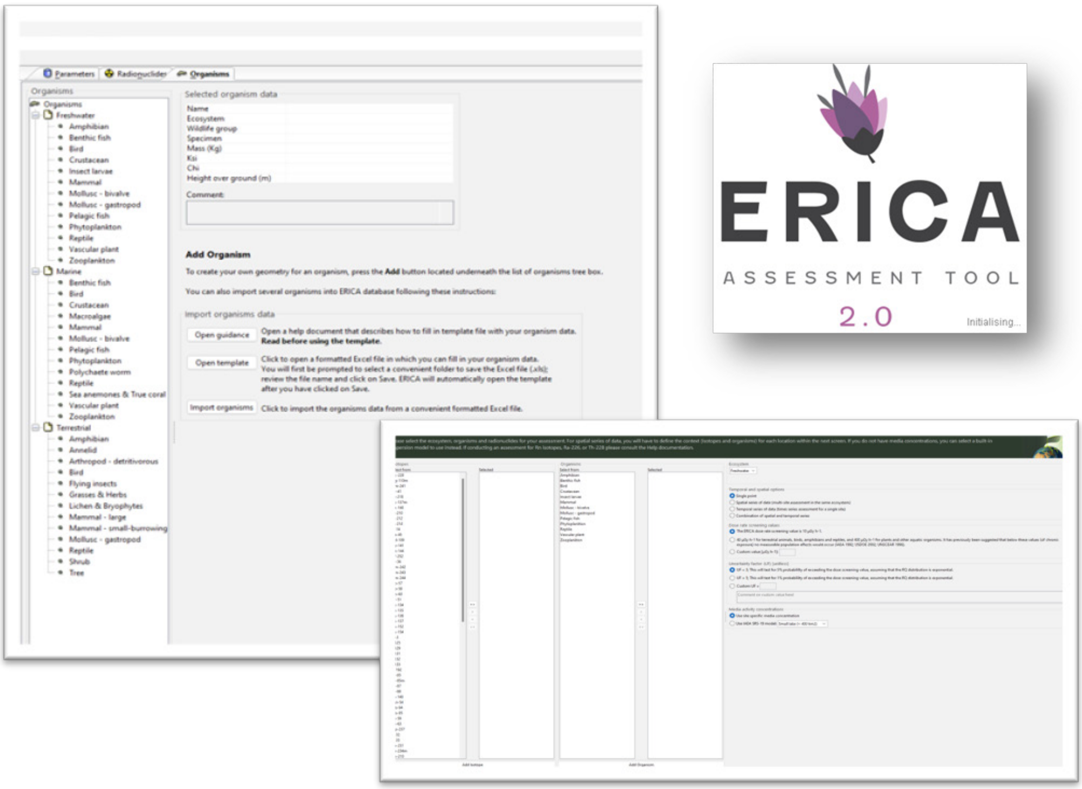


Figure 3-1. *Example ERICA assessment tool (version 2.0) parameter pages*

ERICA Version 2.0 was released in November 2021 and presents the most up to date version of the tool. The Version 2.0 release included:

- New dosimetry, including the implementation of International Commission on Radiological Protection (ICRP) Publication 136 [10] for the calculation of dose coefficients (DCs) for user-defined organisms, and a new approach for the calculation of the dose contribution from short-lived progeny in a decay chain.

- Inclusion of noble gases and radon-222 (Rn-222) and radon-220 (Rn-220), also known as thoron, including dose coefficients for external radiation from immersion in air and internal alpha radiation from inhalation by animals, the calculations for which are available at tier 2 only (see below for details on the ERICA tiers of assessment).
- Updated CRs and Kd values and various other functional enhancements.

There are three tiers of assessment:

- **Tier 1** is a simple and highly conservative screening assessment using maximum activity concentrations in environmental media as input. These are compared against Environmental Media Concentration Limits (EMCL) that have been derived for each radionuclide-reference organism combination by back calculating the environmental concentration of each radionuclide that would give rise to a dose rate consistent with an ERICA screening dose rate value of 10 micro-Grays per hour (µGy/h). The EMCL for the most limiting reference organism within a given ecosystem is applied. Tier 1 is limited to the reference organisms and radionuclides included as defaults within the assessment tool.
- **Tier 2** is a less conservative screening assessment with a greater user-interface that enables a more tailored assessment to be undertaken, including defining representative species in support of site-specific assessments and/or the addition of radionuclides that are not included by default. The habits of organisms (e.g., their position relative to environmental media) and assessment parameters such as the CR and Kd can also be revised for a more site-specific application. Tier 2 is recommended as the entry point for assessments where user-defined representative species are to be assessed or where radionuclides of interest are not included by default.
- **Tier 3** is intended for use in situations where results of tier 2 assessments, following any appropriate assessment refinement, are above the ERICA screening value. It provides the basis for detailed assessments to be undertaken probabilistically using sensitivity analysis. No screening dose rate is applied; rather, output should be compared against available effects data in order to inform judgement on the likely consequences of the calculated dose rates for the organisms of interest. Note, tiers 1 and 3 cannot be applied to noble gases or radon (Rn-222) or thoron (Rn-220).

The ERICA assessment tool includes some simple generic radionuclide transport / dispersion models for aqueous and gaseous emissions (tiers 1 and 2), but also allows inclusion of radionuclide activity concentrations in environmental media (e.g., air, soil, water, sediment), whether derived from environmental monitoring data or other modelling assessments. The assessment approach adopted herein is to capitalise on the activity concentrations predicted in environmental media by the ECOLEGO model as described in Section 2. This ensures that there is a consistent approach to modelling of radionuclide transport between human and non-human biota assessments.

As a result of the radionuclides of interest, the focus of the current assessment is on ERICA tier 2, to enable dose rates from non-default radionuclides to be evaluated, along with dose rates for noble gases, including radon and thoron.

3.1 Conceptual basis for biota assessment

The radiological assessment for non-human biota associated with gaseous and aqueous emissions of radioactivity to the environment is expressed in terms of a dose rate (μGy/h). Typically, biota dose assessments focus on potential impacts to populations rather than individuals such that average exposure rates over a geographical area, relevant to the species considered, are of interest. However, where protected species are present, assessment and protection of individuals in a more localized area may be considered.

Due to the diversity of plants and animals in the environment, it is not feasible to assess the exposure of all species within an area of interest, and a sub-set of 'reference' biota are therefore required. The ERICA assessment tool provides a set of 'reference organisms', which are simplified geometric representations (spheres and ellipsoids) of different types of biota (e.g., fish, bird etc.). In this, organisms are described in terms of length (L), width (W), height (H) and mass as shown in Figure 3-2.

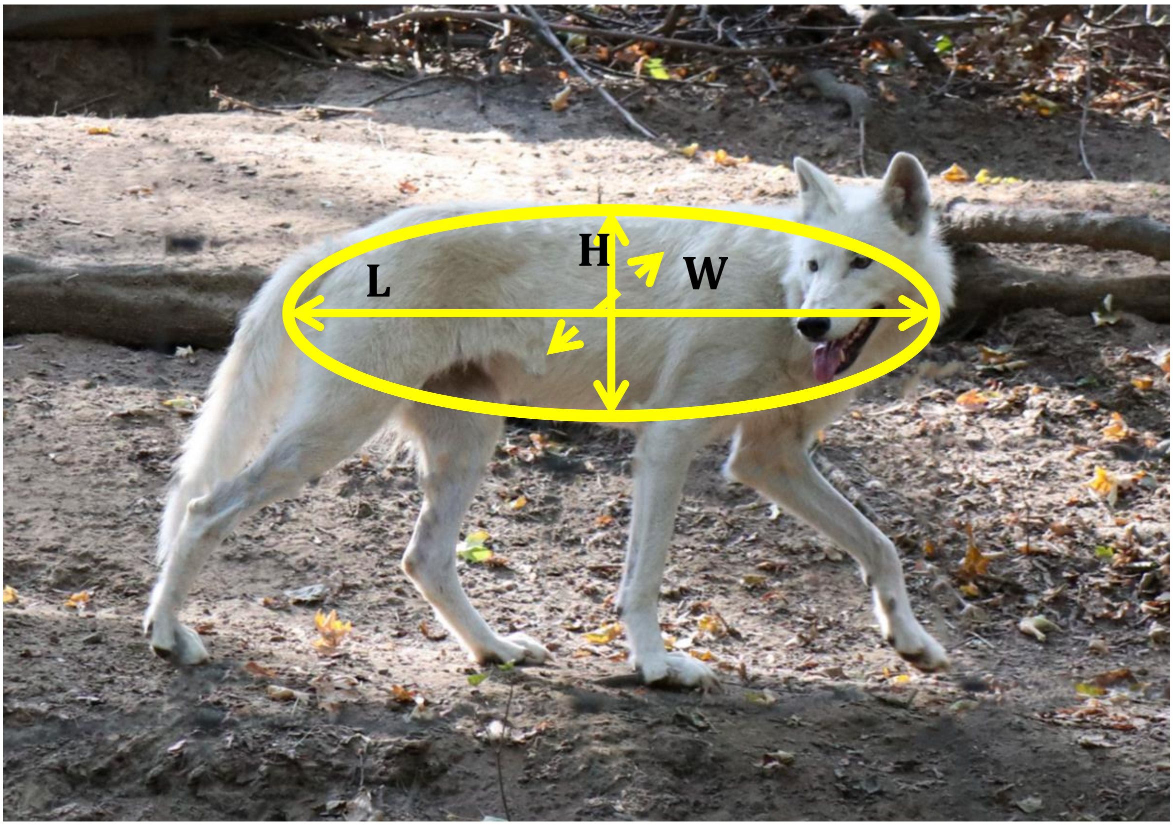


Figure 3-2: *Example of the geometric representation of an organism*

Reference organisms also have generalised occupancy habits within the ecosystems they inhabit (i.e., their position relative to environmental media, namely air, soil, sediment and/or water). As illustrated in Figure 3-3, biota can either be within soil or on/above the soil surface in terrestrial systems, whereas in aquatic systems, biota can be present within sediment, on sediment, within water or on the water surface.

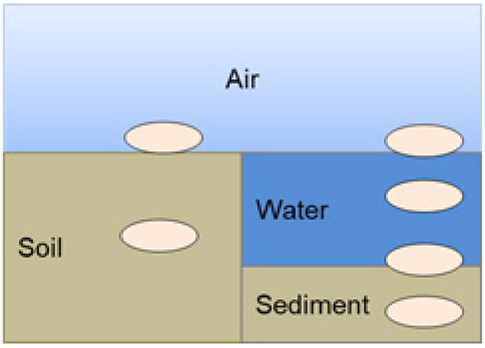


Figure 3-3: *Simplified representation of terrestrial (left) and aquatic (right) ecosystems and possible occupancies of reference organisms relative to environmental media*

The ERICA reference organisms were selected to represent typical types of plant and animal commonly found in terrestrial, freshwater and marine ecosystems throughout Europe. They are not intended as direct representations of any particular species. Reference organisms in terrestrial and freshwater ecosystems are shown in Table 3-1.

Table 3-1: *ERICA reference organisms for terrestrial and freshwater ecosystems*

Freshwater	Terrestrial
Amphibian	Amphibian
Benthic fish	Annelid
Bird	Arthropod - detritivorous
Crustacean	Bird
Insect larvae	Flying insects
Mammal	Grasses and herbs
Mollusc – bivalve	Lichens and bryophytes
Mollusc – gastropod	Mammal - large
Pelagic fish	Mammal – small burrowing
Phytoplankton	Mollusc - gastropod
Reptile[1]	Reptile
Vascular Plant	Shrub
Zooplankton	Tree

The ERICA reference organisms encompass the ICRP Reference Animals and Plants (RAPs) as described in the ICRP Publication 124 'Protection of the Environment under Different Exposure Situations' [11]. Terrestrial and freshwater RAPs are the bee (flying insect), deer (large mammal), duck (bird), earthworm (annelid), frog (amphibian), pine tree (tree), rat (small mammal), salmonid (pelagic fish) and wild grass (grasses and herbs). The ICRP 124 [11] use of RAPs is comparable to the radiation protection concept of 'Reference Man'. A RAP is defined as: 'a hypothetical entity, with the assumed basic biological characteristics of a particular type of animal or plant, as described to the generality of the taxonomic level of

[1] It is noted that although there are a number of terrestrial reptiles in Norway, no freshwater reptiles naturally present were identified. Where results are presented for the freshwater environment, the ERICA default organism of reptile has been retained simply to provide a complete report of the assessment tool results.

Family, with defined anatomical, physiological, and life-history properties, that can be used for the purposes of relating exposure to dose, and dose to effects, for that type of living organism.' It is acknowledged that the RAPs may not be the direct objects of protection per se, however their consideration allows different levels of organism radiosensitivity to be considered.

ICRP 124 [11] suggest using 'representative species' for site-specific assessment. That is, consideration of animal and plant species specific to a particular site. In most instances, site-specific species can be adequately covered by the ERICA reference organisms (inclusive of the ICRP RAPs) where a particular species is 'mapped' to a particular reference organism. However, in some instances it may be appropriate to add new organisms with associated parameters, for example, where species have behaviours not covered by reference organisms that may lead to increased exposure potential or to address stakeholder interests.

Unlike radiation protection of humans, dose 'limits' are not applied to protection of biota. Instead, biota exposures are considered relative to screening values and/or ICRP 'Derived Consideration Reference Levels' (DCRLs).

DCRLs are available for each of the 12 ICRP RAPs and are 'order of magnitude' bands of dose rates that have been set at a level within which there is likely to be some chance of the occurrence of deleterious effects (see Table 3-2).

Table 3-2: *ICRP RAP DCRL Values*

RAP	DCRL (µGy/h)	Planned exposure reference level (µGy/h)
Deer, rat, duck, pine tree	4 – 40	4
Frog, trout, flatfish, grass, seaweed	40 – 400	40
Bee, crab, earthworm	400 – 4,000	400

The DCRLs are not intended to be applied as limits, but rather as points of reference to "inform on the appropriate level of effort that should be expended on environmental protection, dependent on the overall management objectives, the exposure situation, the actual fauna and flora present, and the numbers of individuals thus exposed" [11]. For planned exposure situations[2], the ICRP position is that annually averaged exposures should not exceed the lower band of the DCRL for each RAP [11].

[2] That is, where a situation of exposure has arisen from a planned operation, i.e., an authorised discharge.

In addition to the ICRP DCRLs, ERICA provides a generic incremental screening value of 10 µGy/h; it is applicable to all organisms across all ecosystems. The ERICA screening value was derived statistically from radiation effects data and is set at a level below which deleterious effects on non-human biota are unlikely to occur and is broadly consistent with the DCRLs for the most radiosensitive RAPs.

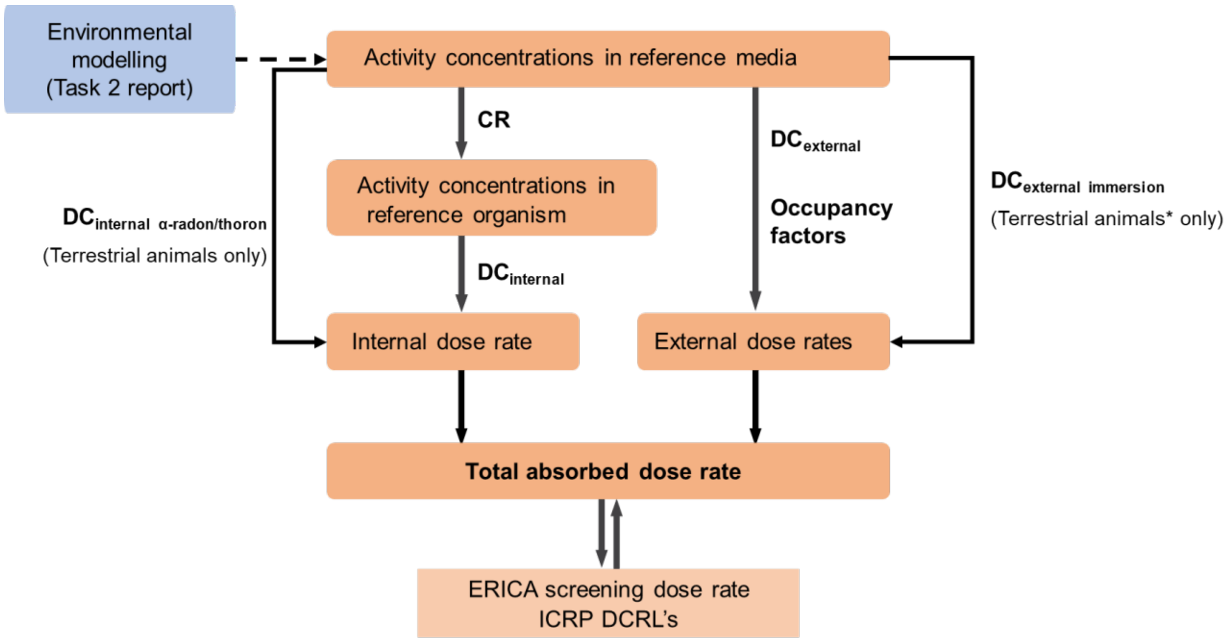
3.2 ERICA dosimetry

The following description of how dose rates are calculated in ERICA is based on the ERICA Version 2.0 helpfile (Last Updated: 28 October 2021). As noted previously, the focus is on ERICA tier 2, which includes immersion doses for noble gases and inhalation doses associated with radon and thoron.

The geometric representation of organisms provides the basis for internal and external DCs to be calculated that are specific to each organism and radionuclide and consider the organisms position in relation to environmental media (soil, air, sediment, water). For terrestrial biota, the environmental media is the soil, except where noble gases, H-3 or C-14 are considered, where the environmental media is the air. For aquatic biota the environmental media is the water and/or sediment.

DCs are defined as the internal or external absorbed dose rates in µGy/h per activity concentration in an organism (Bq/kg) or environmental medium (Bq/kg in soil or sediment, Bq/m^3 in air or Bq/l water). The ICRP BiotaDC [12] calculator has been incorporated within ERICA Version 2.0 for the calculation of DCs. Further information on the calculation of DCs is available from ICRP Publication 136 [10].

The overall approach to calculating dose rates for non-human biota is summarized in Figure 3-4. Details on the calculations underpinning each step are provided in the following sections.



** Applies only to animals with fractional or full occupancy in the above-soil compartment*

Figure 3-4: *ERICA dose rate calculation and evaluation*

3.2.1 Internal dose rate calculation (excluding radon and thoron)

Internal exposure is calculated in relation to the average activity concentrations of radionuclides in environmental media and a CR is applied to estimate the activity concentration in the organism, assuming homogenous distribution, relative to that in environmental media. Internal DCs are then applied to convert the average radionuclide activity concentrations within the body of the reference organism to an internal absorbed dose rate. ERICA provides generic CRs for all default reference organisms and radionuclides. By preference, empirical CR data have been incorporated, with data gaps being necessarily addressed through the application of analogue approaches. Radiation weighting factors are also applied to account for the relative biological effectiveness of alpha (α), low beta (low β) and high beta-gamma (βγ) radiation.

With the exception of radon and thoron, internal ($\dot{D}^{ro}_{int,i}$) absorbed dose-rates (in units of µGy/h), are derived according to the following equation:

$$\dot{D}^{ro}_{int,i} = C^{ro}_i \times \left[w_{low\beta} \times DC^{ro}_{int,low\beta,i} + w_{\beta\gamma} \times DC^{ro}_{int,\beta\gamma,i} + w_\alpha \times DC^{ro}_{int,\alpha,i}\right]$$

Where:

C_i^{ro} is the average concentration of radionuclide *i* in the reference organism '*ro*' (Bq/kg fresh weight),

w_{α}; $w_{low\beta}$; $w_{\beta\gamma}$ are weighting factors for various components of radiation (α, low β and βγ),

$DC_{int,\alpha,i}^{ro}$; $DC_{int,low\beta,i}^{ro}$; $DC_{int,\beta\gamma,i}^{ro}$ are radionuclide specific internal DCs for reference organism 'ro' and radionuclide 'i', and various components of radiation (α, low β and βγ).

The default weighting factors are 10 for alpha radiation, 3 for low-energy beta radiation and 1 for gamma / high-energy beta radiation.

The average activity concentration of a radionuclide in a reference organism (C_i^{ro}) is derived through the application of a CR to the activity concentration of the radionuclide in environmental media, taking account of the physical half-life:

$$C_i^{ro} = CR_{i,wo-media}^{ro} \times eq_{i,\mathrm{ro}} \times C_{zi}^{ref}$$

Where:

C_i^{ro} is the average concentration of radionuclide i in the reference organism 'ro' (Bq/kg fresh weight),

$eq_{i,\mathrm{ro}}$ is the equilibrium correction factor (see below),

C_{zi}^{ref} is the average concentration of radionuclide i in the reference media of a given location z (Bq/kg fresh weight (soil) or Bq/l (water)).

For noble gases (excluding radon and thoron), CRs are set at zero and, as such, the internal dose-rate is calculated as being zero.

Concentration ratios are typically based on data from stable elements or long-lived radionuclides. For radionuclides with short physical half-lives, lower steady state activity concentrations in organisms will be attained due to radioactive decay. As such, an equilibrium correction factor ($eq_{i,ro}$) has been introduced to adjust concentration ratios to account for radioactive decay of short-lived radionuclides:

$$eq_{i,\mathrm{ro}} = \frac{\ln(2)}{\ln(2) + \lambda_i \times T_o}$$

Where:

T_o = biological half-life for organism, i.e., plants = 10 days and for animals = 30 days,

λ_i = physical decay constant (d^{-1}) for radionuclide 'i'.

The equilibrium correction factors (ECF) are included as default parameters. For any radionuclide added to an assessment using ERICA's 'add isotope' function, ECFs are not automatically assigned, and manual addition of factors is not currently supported. As such, internal activity concentrations are likely to be over-estimated for radionuclides with short physical half-lives and, hence, calculated internal dose rates will represent the upper bounding case[3].

3.2.2 Internal dose rate calculation for radon and thoron (terrestrial environment)

For radon and thoron (Rn-222 and Rn-220) in terrestrial assessments, account needs to be taken of the internal dose associated with inhalation and deposition of these radionuclides (and their progeny) in the lung (or lung like organ) of animal species.

Alpha particles contribute around 95% of the total emitted energy of radon progeny. Therefore, for the sake of simplicity and of conservatism, ERICA assumes that alpha particles contribute 100% of the total emitted energy of radon progeny, with the same assumption being applied to both Rn-222 and Rn-220.

The calculation method employed in ERICA for Rn-222 and Rn-220 is based on an allometric approach described in Vives i Batlle et al. (2017) [13]. The following formula is used in ERICA to calculate internal weighted doses, $\dot{D}^{ro}_{int,weighted,i}$:

$$\dot{D}^{ro}_{int,weighted,i} = \left(w_\alpha \times DC^{ro}_{int,\alpha-Rn,i}\right) \times C^{a}_{Rn}$$

Where:

w_α = alpha radiation weighting factor,

$DC^{ro}_{int,\alpha-Rn,i}$ = DC for internal alpha radiation for radon or thoron (µGy/h per Bq/m^3) for given reference organism 'ro',

C^{a}_{Rn} = activity concentration of radon or thoron in air (Bq/m^3).

[3] The implications of ECFs for short-lived non-default radionuclides are discussed with respect to results in Section 5.

The allometric equations used in derivation of animal Rn-222 and Rn-220 'inhalation' DCs are relevant specifically for mammals but have been extrapolated to terrestrial invertebrate reference organisms. The use of these DCs for non-mammals should therefore be considered as illustrative. For in-soil organisms, the Rn-222 or Rn-220 activity concentrations in soil air are assumed to be the same as that in air above the soil surface.

Due to uncertainties in the application of inhalation dose rate dosimetry to plants, no DCs are available in ERICA for terrestrial plants (grasses and herbs, shrub and trees).

3.2.3 External dose rate calculation

External absorbed dose rates are calculated using the external DCs for each organism and radionuclide of interest, the average concentration of radionuclides in the environmental media they inhabit and the occupancy factors that account for the proportion of time spent in positions relative to environmental media. For example, a small burrowing mammal may spend a proportion of time within soil and a proportion of time in the above-soil compartment, which is expressed through the use of occupancy factors. For aquatic environments, a Kd is applied to account for the partitioning of radionuclides between sediment and water and hence the external dose from different parts of the aquatic ecosystem.

In previous versions of ERICA (up to version 1.3), weighting factors were also applied to components of external radiation where the contribution to external dose from alpha radiation was assumed to be zero, reflecting the short path lengths of alpha particles in environmental media and the absorbing properties of 'protective' layers of skin, scales, feathers and fur of many of the reference organisms considered. However, in version 2.0 of ERICA, the splitting of radiation into low β and β/γ was considered unnecessary and single component external DCs have therefore been employed. As such, for aquatic systems, the external dose rate ($\dot{D}^{ro}_{ext,i}$) is calculated according to the following equation:

$$\dot{D}^{ro}_{ext,i} = DC^{ro}_{ext,aqu,i} \times [(v^{ro}_{wat} + 0.5 \times v^{ro}_{wat.surf} + 0.5 \times v^{ro}_{sed.surf}) \times C_{wat,i} + (0.5 \times v^{ro}_{sed.surf} + v^{ro}_{sed}) \times C_{sed,i}]$$

Where:

$DC^{ro}_{ext,aqu,i}$ = external DCs for aquatic environments for reference organism '*ro*' and radionuclide '*i*' in µGy/h per Bq/L (if water) or µGy/h per Bq/kg (if sediment). It is assumed that the activity concentration units are interchangeable since 1 L of freshwater has a mass of approximately 1 kg,

v^{ro}_{wat}; $v^{ro}_{wat.surf}$; $v^{ro}_{sed.surf}$; v^{ro}_{sed} = occupancy factors for reference organism '*ro*' in the water column, at the water surface, at the sediment surface and in sediment respectively,

$C_{wat,i}$; $C_{sed,i}$ = activity concentrations of radionuclide '*i*' in water (Bq/l) and in sediment (Bq/kg) respectively.

For terrestrial systems the external dose rate ($\dot{D}^{ro}_{ext,i}$) is calculated as follows:

$$\dot{D}^{ro}_{ext,i} = \left(DC^{ro}_{ext,InSoil,i} \times v^{ro}_{InSoil} + DC^{ro}_{ext,OnSoil,i} \times v^{ro}_{OnSoil} + DC^{ro}_{ext,InAir,i} \times v^{ro}_{InAir}\right) \times C_{soil,i}$$

Where:

v^{ro}_{InSoil}; v^{ro}_{OnSoil}; v^{ro}_{InAir} = occupancy factors for reference organism '*ro*' for locations 'In soil', 'On soil' and 'In air' respectively,

$DC^{ro}_{ext,InSoil,i}$; $DC^{ro}_{ext,OnSoil,i}$; $DC^{ro}_{ext,InAir,i}$ = external DCs for reference organism '*ro*' and radionuclide '*i*' in µGy/h per Bq/kg for 'In soil' and 'On soil' or µGy/h per Bq/m^3 'In air' respectively,

$C_{soil,i}$ = activity concentration of radionuclide in soil (Bq/kg).

In the exceptional cases of calculating external dose-rates from short-lived progeny (physical half-lives under 10 days) that are included by default as part of a decay chain, a modification to the calculation is required to account for the decay of unsupported, short-lived progeny (in soil, water and sediment) over the integration period (1-year) as their contribution to external dose (via ingrowth) will be captured within the external DC of the parent. A media average activity correction factor ($ma_{s,i}$) has therefore been incorporated in ERICA Version 2 for short-lived progeny in decay series, such that the following equations apply:

For aquatic systems:

$$\dot{D}^{ro}_{ext,i} = DCC^{ro}_{ext,aqu,i} \times [\left(v^{ro}_{wat} + 0.5 \times v^{ro}_{wat.surf} + 0.5 \times v^{ro}_{sed.surf}\right) \times C_{wat,i} + \left(0.5 \times v^{ro}_{sed.surf} + v^{ro}_{sed}\right) \times C_{sed,i}] \times ma_{s,i}$$

For terrestrial systems:

$$\dot{D}^{ro}_{ext,weighted,i} = \left(DCC^{ro}_{ext,InSoil,i} \times v^{ro}_{InSoil} + DCC^{ro}_{ext,OnSoil,i} \times v^{ro}_{OnSoil} + DCC^{ro}_{ext,InAir,i} \times v^{ro}_{InAir}\right) \times C_{soil,i} \times ma_{s,i}$$

Unlike equilibrium correction factors, media average activity correction factors are only applied to radionuclides with very short physical half-lives that are included by default in decay series. This is due to activity concentrations for progeny not being entered directly by an assessor as (average) activity concentration over the integration period but being derived as ancillary information via models.

In the case of noble gases (including radon and thoron), in terrestrial ecosystems for which media concentration data are entered as radionuclide activity concentrations in air, an immersion (i.e., above soil submersion in contaminated air) DC is applied. The DCs are applied only to animals assigned either a fractional or fully on soil occupancy (immersion dose rates are not currently calculated for plants in ERICA). It is assumed that animals are 100% of the time present in contaminated air (irrespective of whether the organism is above or below ground), meaning that occupancy factors are ignored. The calculation of external dose-rate therefore simplifies to:

$$\dot{D}^{ro}_{ext} = \sum_i C_i^{ref*} \times DC^{ro}_{ext-imm,i}$$

Where:

C_{zi}^{ref*} = the average concentration of radionuclide *i* in the reference media – air (Bq/m^3 (air)),

$DC^{ro}_{ext-imm,i}$ = the DC for external exposure from immersion in contaminated air defined as the ratio between the average activity concentration of radionuclide *i* in air corresponding to the dose rate to organism '*ro*' (μGy/h per Bq/m^3).

3.2.4 Total dose rates and their evaluation

The total (weighted) absorbed dose-rate ($\dot{D}^{ro}_{Tot}$) is calculated for each organism as the sum of external and internal weighted dose rates across all radionuclides (from 1 to i):

$$\dot{D}^{ro}_{Tot} = \sum_1^i \dot{D}^{ro}_{int,i} + \sum_1^i \dot{D}^{ro}_{ext,i}$$

Total dose rates are then compared against a default incremental screening dose rate of 10 μGy/h and/or a RAP DCRL. A comparison of calculated dose rates against natural background and/or an evaluation of radiation effects data can also be undertaken as a means of evaluating the potential impact to species of non-human biota. Alternatively, where calculated dose rates exceed screening values/benchmarks, further assessment may be deemed appropriate. This could involve a further tier 2 assessment with efforts made to reduce inherent uncertainties (e.g. use of more site-specific data) or progression to a tier 3 assessment.

4 ERICA parameterization for the IFE Kjeller assessment

As noted previously, it is not feasible to evaluate potential exposures of all species in the environment. A subset of species are therefore used for evaluation purposes. Whilst RAPs and reference organisms have been developed to allow exposures and effects of ionising radiation to be evaluated, ICRP suggest the use of species representative of those in the local environment for site-specific assessments (i.e. representative species), recognizing that those representative species may be very similar to RAPs/reference organisms or very different [11]. The approach taken to select representative species in terrestrial and aquatic environments in the vicinity of the IFE Kjeller site is detailed below, along with information on their parameterization for assessment purposes.

4.1 Identification of representative species for assessment

Species that are representative of the local environments around the Kjeller site were identified using a tiered approach.

Initially, species associated with important and protected habitats in the terrestrial environment around Kjeller and downstream of the liquid effluent discharge point in the Nitelva River were identified using the interactive maps available from Environment Norway [14]. Results are presented in Figure 4-1. Management areas for carnivores were also identified. For each identified area, Environment Norway information supporting the designation was reviewed and species associated with the designations identified.

In addition to researching species associated with designated areas, recorded observations of endangered, vulnerable and threatened species in the area of Lillestrøm Creek, which encompasses the area around Kjeller and the municipality of Lillestrøm, were identified using the interactive Norway's Species Map Service from the Norwegian Biodiversity Information Centre [15]. A list of observations for the period 2000 to 2022 was generated using the interactive map. The observations during this period are illustrated in Figure 4-2.

Finally, the same interactive map for Lillestrøm Creek was used to list additional species that are not classified as endangered, vulnerable or threatened, but generally associated with the terrestrial and freshwater environments around the IFE-Kjeller site, based on recorded observations. Some of the most commonly observed species were then selected as representative species for assessment, focussing on plant and animal categories (based on the categories of freshwater and terrestrial biota within the ERICA assessment tool) with no or few species identified based on the previous review stages, to ensure key species groups and trophic levels within broad terrestrial and aquatic food webs were represented.

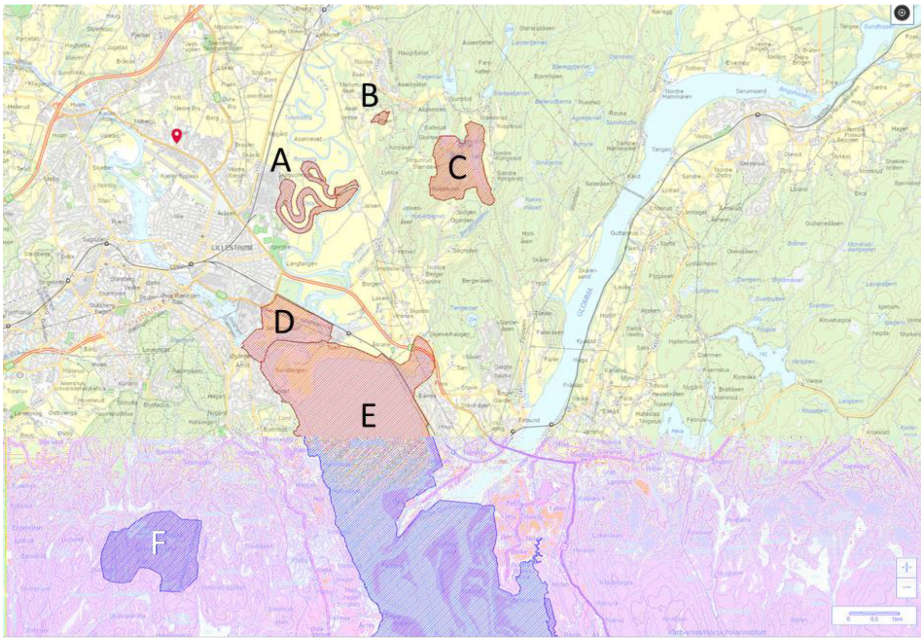


Figure 4-1: *Protected areas in the vicinity of the Kjeller [15]. A – Stilla og Brauterstilla; B – Flaen; C – Kongsrudtjern; D – Sørumsneset; E – Nordre Øyeren; F – Ramstadslottet.*

General descriptions of terrestrial and freshwater habitats are provided below, along with the representative species selected for assessment.

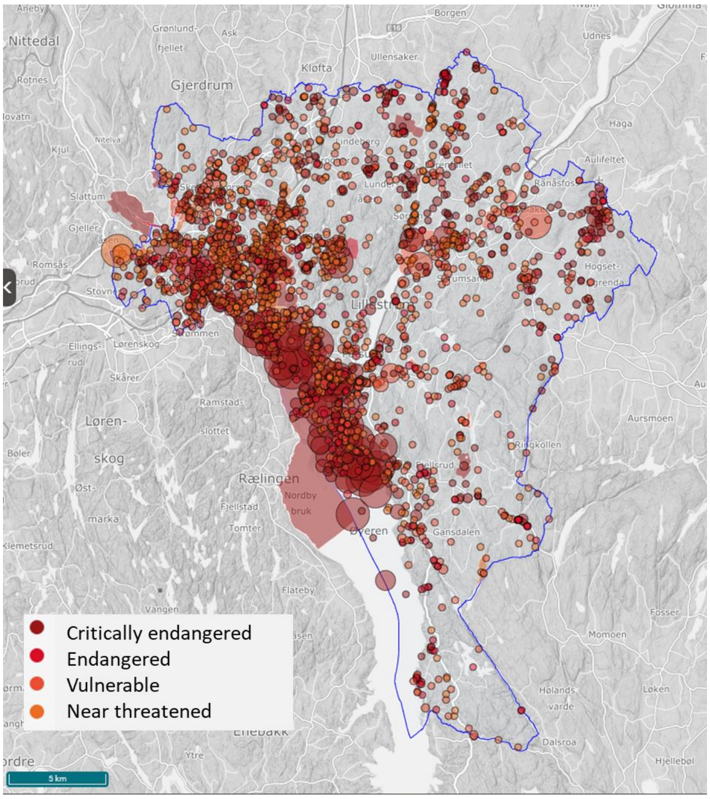


Figure 4-2: *Observations of endangered, vulnerable and threatened (red-list) species in the area of Lillestrøm Creek in the period 2000 – 2022 [15].*

4.1.1 Terrestrial habitats and representative species

The terrestrial areas of the site are comprised of coniferous and deciduous forests, grasslands and meadows that support a rich plant and animal diversity, including the red-listed species almond willow (*Salix triandra*) and northern goshawk (*Accipiter gentilis*) [16]. Northern Lake Øyeren also falls within management areas for lynx (*Lynx lynx*) and grey wolf (*Canis lupus*), as illustrated in Figure 4-3.

Figure 4-3: *Management area for wolf [17].*

Two forests located approximately 4-5 km to the east of Kjeller are designated as protected areas (marked B and C in Figure 4-1). These are the Flaen and Kongsrudtjern nature reserves. Flaen nature reserve is a swamp and spring forest that is important for biodiversity. The forest is dominated by gray alder and is species-rich in terms of birds [17]. The Kongsrudtjern nature reserve is a coniferous forest area with diverse plant species, including several important lichen and moss species. There are also valuable amphibian and insect fauna present, including several endangered and vulnerable species. Marsh areas are also present.

In addition to protected forest areas, wetlands and riparian zones associated with the Nordre Øyeren and Sørumsneset nature reserves provide habitats for a wide range of terrestrial species. Large parts of the nature reserve are associated with forest and meadow areas. Willow (*Salix* spp) and birch dominate forest areas. The meadows provide habitat for a wide range of plant species, including red-listed species such as nodding bur-marigold (*Bidens cernua*) and meadow starwort (*Stellaria palustris*) and for wading birds that feed on the mudflats, including Eurasian curlew (*N. arquata*), northern lapwing (*V. vanellus*) and black-headed gull (*Chroicocephalus ridibundus*). Semi-aquatic species water vole (*Arvicola amphibius*) and European beaver (*Castor fiber*) are also associated with these areas.

Other species identified with the terrestrial environment around Kjeller include roe deer (*Capreolus capreolus*), moose (*Alces alces*), long-eared owl (*Asio otus*) and white-backed woodpecker (*Dendrocopos leucotos*). Several red-listed bumblebees are also present, including great yellow bumblebee (*Bombus distinguendus*) and brown-banded carder bee (*B. humilis*) [18].

Other species identified with the area that inhabit terrestrial habitats, as identified from the interactive map service of the Norwegian Biodiversity Information Centre [15], include mammals such as red fox (*Vulpes vulpes*), European badger (*Meles meles*), European hedgehog (*Erinaceus europaeus*), and reptiles such as grass snake (*Natrix natrix*) and common lizard (*Zootoca vivipara*). Several amphibian species have also been identified in the area that can be associated with both terrestrial and freshwater habitats, including common frog (*Rana temporaria*) and moor frog (*Rana arvalis*).

Representative species associated with the terrestrial habitats of the area are listed in Table 4-1 and each species mapped onto the relevant ERICA reference organism. However, where significant differences were evident between the representative species and reference organisms in terms of size, new representative organisms (noted as 'user-defined representative species' in Table 4-1) were generated using the 'add organism' function within the ERICA assessment tool. Information on the dimensions and mass and occupancy habits of ERICA default reference organisms are provided in Appendix A. Dimensions and mass of user-defined representative species are presented in Section 4.2.

Table 4-1: *Terrestrial representative species selected for assessment and mapping to ERICA reference organisms. (Note on Red-list status: EN – endangered; VU – vulnerable; NT – near threatened; LC – least concern)*

ERICA reference organism	Representative species	Latin name	Red-list status
Amphibian	Common frog	*Rana temporaria*	LC
	Moor frog	*Rana arvalis*	VU
	Northern crested newt	*Triturus cristatus*	NT
Annelid	Earthworms	*Lumbricus terrestria*	LC
Arthropod	Beetle	*Ampedus sanguinolentus*	EN
	Beetle	*Lordithon pulchellus*	VU
	Blister beetle	*Apalus bimaculatus*	NT
Bird	Northern goshawk	*Accipiter gentilis*	VU
	Eurasian curlew	*Numenius arquata*	EN
	Northern lapwing	*Vanellus vanellus*	CR
	Black-headed gull	*Chroicocephalus ridibundus*	CR
	Long-eared owl	*Asio otus*	LC

ERICA reference organism	Representative species	Latin name	Red-list status
	White-backed woodpecker	*Dendrocopos leucotos*	LC
Flying insect	Great yellow bumblebee	*Bombus distinguendus*	EN
	Brown-banded carder bee	*Bombus humilis*	LC
	Dragonflies	*Sympetrum spp.*	LC
	Caddis fly	*Lype reducta*	NT
Grasses & herbs	Nodding bur-marigold	*Bidens cernua*	EN
	Meadow starwort	*Stellaria palustris*	VU
	Creeping lady's-tresses	*Goodyera repens*	NT
	Meadow oat-grass	*Avenula pratensis*	NT
Lichen & bryophyte	Feather flat moss	*Neckera pennata*	VU
	New England bryhnia moss	*Brachythecium novae-angliae*	NT
	Campylium moss	*Pseudocampylium radicale*	EN
	Foliose lichen	*Physcia tenella*	LC
	Witch's-hair lichen	*Alectoria sarmentosa*	NT
Mammal (large)	Moose	*Alces alces*	LC
Mammal (small burrowing)	Water vole	*Arvicola amphibius*	LC
	European hedgehog	*Erinaceus europaeus*	NT
	Yellow-necked mouse	*Apodemus flavicollis*	LC
	Field vole	*Microtus agrestis*	LC
Gastropod mollusc	Copse snail	*Arianta arbustorum*	LC
	Door snail	*Macrogastra ventricosa*	NT
Reptile	Grass snake	*Natrix natrix*	LC
Shrub	Almond willow	*Salix triandra*	NT
	Common juniper	*Juniperus communis*	LC
Tree	Almond willow	*Salix triandra*	NT
	Silver birch	*Betula pendula pendula*	LC
	Gray alder	*Alnus incana*	LC
	European ash	*Fraxinus excelsior*	EN
	Norway spruce	*Picea abies*	LC
User-defined representative species			
Mammal (medium)	Lynx	*Lynx lynx*	EN
	Grey wolf	*Canis lupus*	CR

ERICA reference organism	Representative species	Latin name	Red-list status
	Roe deer	*Capreolus capreolus*	LC
Mammal – large burrowing	Red fox	*Vulpes vulpes*	LC
	European badger	*Meles meles*	LC
Semi-aquatic mammal	European beaver	*Castor fiber*	LC
Reptile (small)	Common lizard	*Zootoca vivipara*	LC

4.1.2 Aquatic habitats and representative species

The Nitelva River is classed as an important stream habitat within an intensively managed agricultural landscape (Designation BN00016174 [19]) and as a species functional area for game (Designation BA00046949 [20]). The habitat comprises the Nitelva River and the associated riparian zone. Over 70 plant species have been recorded, including sedges and grasses and floating-leaf plants. The red-listed species fen violet (*Viola stagnina*) and meadow starwort (*Stellaria* palustris) are present [20].

The Nitelva River is also designated as a species functional area for overwintering and migratory birds including mallard (*Anas platyrhynchos*), and greater scaup (*Aythya marila*), which is a vulnerable, red-listed species [21]. Common frog (*Rana temporaria*) and moor frog (*Rana arvalis*) are also associated with the area.

The river flows in a south easterly direction to Lake Øyeren. On passing Lillestrøm, the river flows through the Sørumsneset nature reserve (Designation VV00000638), a wetland of particular importance for its rich bird life [21]. Here, the river meets with the River Leira before flowing to the Svelle mudflat area, classed as an important habitat for vascular plants, game, fish and clams (Designation BN00071129 [21]). At the base of the Svelle mudflat, the river combines with the River Glomma before reaching Lake Øyeren, which is northern Europe's largest inland delta and Norway's most species-rich lake [22]. Together, the Svelle and northern area of lake Øyeren form the Nordre Øyeren nature reserve, which is classified as a wetland of international importance under the Ramsar Convention[4] (Figure 4-4).

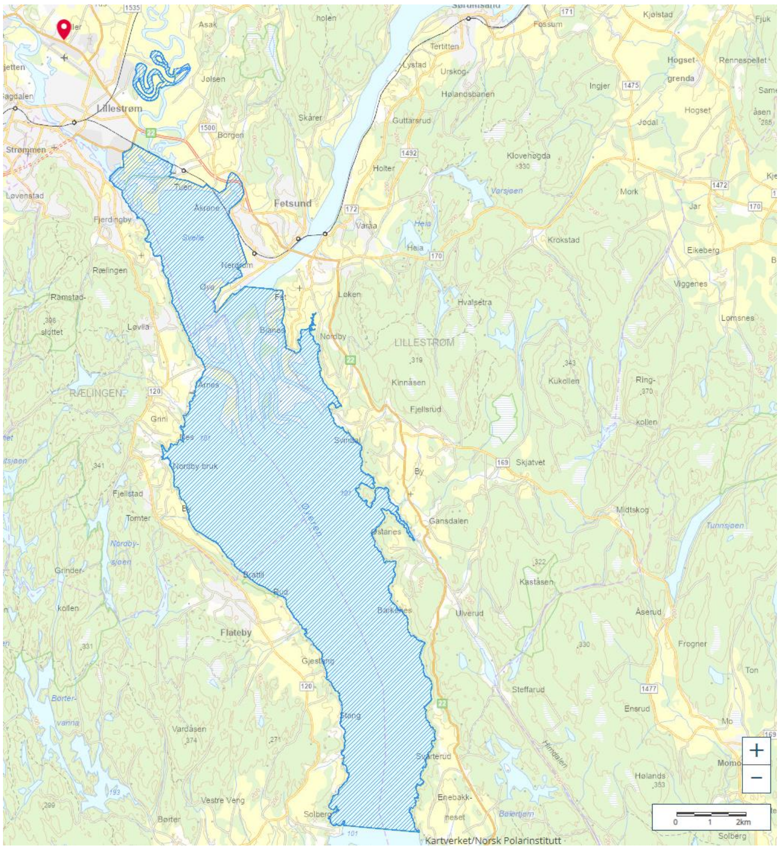


Figure 4-4: *Location of the Norde Øyeren Ramsar Site [14].*

The Nordre Øyeren nature reserve includes low-lying islands and land adjacent to Lake Øyeren and represents a rich and complex wetland system of branched rivers, swamps, lagoons, islands and canals [23]. The area provides an important wetland habitat for a wide range of bird species, including the red-listed species Eurasian coot (*Fulica atra*), common moorhen (*Gallinula chloropus*), Eurasian curlew (*Numenius arquata*), northern lapwing (*Vanellus vanellus*) and black-headed gull (*Chroicocephalus ridibundus*) [24].

[4] The Convention on Wetlands (Ramsar Convention) is an intergovernmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources.

The water level of Lake Øyeren varies seasonally, giving rise to mudflats in both spring and autumn that provide an important feeding resource for migratory birds, such as greylag goose (*Anser anser*) and the area, together with the lower Nitelva River, provides the most important wintering area for whooper swans (*Cygnus cygnus*) in Norway. The site also supports large populations of fish and benthic organisms. Species associated with the area include northern pike (*Esox lucius*), common perch (*Perca fluviatilis*), duck mussel (*Anodonta anatina*), depressed river mussel (Pseudanodonta complanata), rams horn snail (*Gyraulus acronicus*) and European crayfish (*Astacus astacus*). The semi-aquatic species European beaver (*Castor fiber*) and European water vole (*Arvicola amphibius*) are also associated with the area.

Representative species associated with the freshwater habitats of the area are listed in Table 4-2 and each species mapped onto the relevant ERICA reference organism. Consistent with the approach for terrestrial representative species, where significant differences were evident between the representative species and reference organisms in terms of size, new representative organisms (noted as 'user-defined representative species' in Table 4-2) were generated using the 'add organism' function within the ERICA assessment tool. Information on the dimensions and mass and occupancy habits of ERICA default reference organisms are provided in Appendix A. Dimensions and mass of user-defined representative species are presented in Section 4.2.

Table 4-2: *Freshwater representative species selected for assessment and their mapping to ERICA reference organisms. (Note on Red-list status: EN – endangered; VU – vulnerable; NT – near threatened; LC – least concern)*

ERICA reference organism	Representative species	Latin name	Red-list status
Amphibian	Common frog	*Rana temporaria*	LC
	Moor frog	*Rana arvalis*	VU
	Northern crested newt	*Triturus cristatus*	NT
Benthic fish	Common rudd	*Scardinius erythrophthalmus*	LC
	Common bream	*Abramis brama*	LC
	Eurasian ruffe	*Gymnocephalus cernuus*	LC
Bird	Eurasian coot	*Fulica atra*	VU
	Mallard	*Anas platyrhynchos*	LC
	Greater scaup	*Aythya marila*	EN
	Common moorhen	*Gallinula chloropus*	VU
	Greylag goose	*Anser anser*	LC
Crustacean	Water sowbug	*Asellus aquaticus*	LC

ERICA reference organism	Representative species	Latin name	Red-list status
Insect larvae	Dragonflies	*Sympetrum spp.*	LC
	Caddis fly	*Lype reducta*	NT
Mammal	Beaver	*Castor fiber*	LC
Bivalve mollusc	Duck mussel	*Anodonta anatina*	LC
	Depressed river mussel	*Pseudanodonta complanata*	LC
Gastropod mollusc	Rams horn snail	*Gyraulus acronicus*	LC
Pelagic fish	European perch	*Perca fluviatilis*	LC
	Common roach	*Rutilus rutilus*	LC
	Northern pike	*Esox lucius*	LC
Phytoplankton	Green algae	*Microspora amoena* *Ulothrix zonata*	LC
Reptile	*Not applicable**		
Vascular plant	Stonewort	*Nitella mucronata*	NT
	Water pygmyweed	*Crassula aquatica*	VU
	Mudwort	*Elatine triandra*	EN
	Lesser pondweed	*Potamogeton pusillus*	EN
Zooplankton	Water flea	*Daphnia spp.*	LC
User-defined representative species			
Large crustacean	European crayfish	*Astacus astacus*	EN
Large bird	Whooper swan	*Cygnus cygnus*	LC
	Greylag goose	*Anser anser*	LC
Small mammal	European water vole	*Arvicola amphibius*	LC

** No freshwater reptile species were identified from searches. Nonetheless, the ERICA reptile reference organism has been included in the assessment for completeness.*

4.2 Parameterization of representative species

Key organism-specific assessment parameters for calculating dose rates to non-human biota are dose coefficients (DC, calculated within ERICA according to assigned dimensions and mass for each reference organism/representative species), occupancy factors and CRs and associated ECFs for short-lived radionuclides. Most of the representative species selected for assessment have been mapped to ERICA reference organisms and the default assessment parameters within the ERICA assessment tool have been applied. The parameters used to represent reference organisms are detailed in Appendix A.

For the user-defined terrestrial and freshwater representative species, detailed in Table 4-1 and Table 4-2 respectively, DCs were generated using the 'add organism' function within the ERICA assessment tool. Where several representative species have been grouped (e.g. lynx, grey wolf and roe deer within the category of 'medium mammal'), a single species has been selected to represent the category. The dimensions and mass of each user-defined representative species used to generate DCs are detailed in Table 4-3.

Default occupancy factors in ERICA have been set to ensure a precautionary screening assessment. For example, occupancy of the aquatic reference organism 'bird' is set to 100% of time being spent within the water column (see Appendix A) to maximize exposure to radioactivity within the water rather than on the water surface (note, assessment of activity in air is considered only in terrestrial ecosystem assessments). A similar precautionary approach has been taken with respect to the occupancy factors assigned to the user-defined representative species (see Table 4-3) such that, for example, the terrestrial large burrowing mammal has been assigned only in-soil occupancy[5].

Concentration ratios for user-defined representative species have been assigned from the closest ERICA reference organism, as detailed in Table 4-3.

Table 4-3: *Parameterization of user-defined representative species*

Representative species	Dimensions and Mass	Data source / justification	Habitat occupancy	Concentration ratios
Terrestrial ecosystem				
Mammal (medium)	Length: 80 cm Width: 10 cm Height: 60 cm Mass: 25 kg	*Lynx selected as representative of this category. Dimensions and mass from [25]*	On soil	ERICA mammal
Mammal – large burrowing	Length: 40 cm Width: 15 cm Height: 20 cm Mass: 6.6 kg	*Red fox selected as representative of this category (largest mass permissible for in soil occupancy in ERICA). Dimensions and mass from [26]*	In soil	ERICA mammal

[5] Such an assumption does not prevent dose rates being calculated for noble gases, including radon and thoron, in terrestrial ecosystems, since occupancy factors are excluded from these calculations.

Representative species	Dimensions and Mass	Data source / justification	Habitat occupancy	Concentration ratios
Semi-aquatic mammal	Length - 33 cm Width - 15 cm Height - 15 cm Mass – 3.9 kg	*Dimensions and mass from freshwater mammal*	On soil	ERICA mammal
Reptile (small)	Length: 7 cm Width: 0.75 cm Height: 0.75 cm Mass: 0.005 kg	*Length and mass from [27].* Width and height estimated.	In soil	ERICA reptile
Freshwater ecosystem				
Large crustacean	Length: 14 cm Width: 2.8 cm Height: 3.5 cm Mass: 0.12 kg	*Length is average of male and female [28] with width, height and mass scaled from signal crayfish in [29]. Nocturnal in habit spending time in burrow during day.*	50% sediment surface, 50% in Sediment	ERICA Crustacean
Large bird	Length: 75 cm Width: 40 cm Height: 30 cm Mass: 9 kg	Whooper swan dimensions/mass selected as the largest of the bird representative species *Estimate (average length ca. 150 cm of which neck/head assumed to be half). Width and height estimated. Mass range 8-11 kg [30].*	In water	ERICA bird
Small mammal	Length: 20 cm Width: 6 cm Height:5 cm Mass: 0.31 kg	*Dimensions and mass from terrestrial small burrowing mammal*	In water	ERICA mammal

4.3 Addressing data gaps in radionuclide-specific parameters

The ERICA assessment tool includes a library of default radionuclides and associated assessment parameters (CRs and, for aquatic ecosystems, Kds). In the case of radionuclide decay series, where progeny have very short physical half-lives (less than 10 days), selection of the parent radionuclide results in dose rates for short-lived progeny also being calculated[6] automatically on the assumption of secular equilibrium between parent and progeny. Whilst explicit selection of short-lived progeny is possible, the ERICA help file cautions against this due to the required input of the unsupported fraction of short-lived radionuclides in environmental media. As such, for radionuclide decay series that are available by default within ERICA, only the parent radionuclide has been explicitly selected, with dose rates for very short-lived progeny being automatically calculated within ERICA. Where longer-lived decay products are relevant, these need to be assessed separately and explicitly included in the assessment.

For radionuclides that are not included by default, ERICA provides an 'add isotope' function that results in the calculation of DCs for all reference organisms (and, where applicable user-defined representative species) for the radionuclide(s) of interest. However, when adding radionuclides, any short-lived progeny within decay series are not automatically added, and each radionuclide must therefore be added and assessed explicitly.

For any added radionuclides, CRs are required, as well as Kd values for aquatic ecosystem assessments. If an added radionuclides is an isotope of an element that is included by default within ERICA, these parameters are automatically available for the new radionuclide since these parameters are element rather than isotope specific. However, where element data are not available by default, parameters must be added.

Radionuclide activity concentrations in both sediment and water for aquatic discharges were extracted from the Ecolego model and both sets of environmental activity concentration data were entered into ERICA. Therefore, in this assessment, the Kd values within ERICA are essentially redundant. Nonetheless, an assessment cannot progress where data for parameters are missing. Therefore, for added radionuclides for which ERICA default Kd values were unavailable, Kd values applied within the Ecolego model have been used. These values and their sources are detailed in the Task 2 report [4].

For CRs, a tiered approach to addressing data gaps has been applied. Where available, CRs for elements and each reference organism have been selected by preference from the Wildlife Transfer Database (WTD) [31]. For any remaining data gaps, analogue approaches have been applied. The analogues applied to address data gaps in CR values are discussed with respect

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[6] Excludes Rn-220 in the Th-228 decay series and Rn-222 in the Ra-226 decay series. Dose rates for Rn-220 and Rn-222 are only calculated when these radionuclides are included explicitly within an assessment.

to the assessments for each IFE division (see Section 5). The CRs applied as default within ERICA are detailed in Appendix A.

As noted in Section 3.2.1, ECFs are applied within ERICA to adjust CRs to account for radioactive decay of short-lived radionuclides. At the current time, inclusion of ECFs for non-default short-lived radionuclides is not supported in ERICA such that dose rates for user-added short-lived radionuclides will be overestimated. To evaluate the implications of the exclusion of ECFs for non-default radionuclides where relevant in the assessment, ECFs have been manually calculated in MS Excel, using the equation outlined in Section 3.2.1, for each non-default radionuclide. These factors, where relevant, are detailed in Appendix A and discussed with respect to total dose rates calculated for atmospheric and liquid effluent discharges from each division where appropriate.

4.4 Processing of Ecolego environmental concentration data

The following activities were undertaken to process the Ecolego data for input into ERICA.

- **Data sorting** – radionuclide data is ideally input into ERICA in alphabetical order (rather than in order of mass number). Therefore, Ecolego results were first sorted to put them in alphabetical order.
- **Deriving annual averaged environmental activity concentrations** – as previously noted, approaches for dynamic (short-term) biota exposure assessments do not exist and ERICA is based on biota exposure averaged over the course of a year. Therefore, the following averages were derived:
    - **Air activity concentrations** vary through a year due to different meteorological conditions and were provided as monthly maximum activity concentrations over a year where this monthly variation is repeated on a year-by-year basis over 60-years. The model results were therefore averaged to give, per radionuclide, single annually averaged values.
    - **Topsoil activity concentrations** were provided on a ca. 5-hour basis over a modelled period of 60-years. Due to atmospheric deposition, soil activity concentrations increase slowly over time until an equilibrium point is reached. The model results were therefore averaged to give, per radionuclide, annually averaged values at 1-year, 5-years, 10-years, 30-years and 60-years.
    - **Water activity concentrations** were provided on a ca. 5-hour basis over a modelled period of 60-years. Water activity concentrations vary through a year, peaking each time a discharge is made, there was however, no long-term

increase or decrease in water activity concentrations. The model results were therefore averaged to give, per radionuclide, single annually averaged values.

- **Sediment activity concentrations** were provided on a ca. 5-hour basis over a modelled period of 60-years. Due to water-sediment exchange process, sediment activity concentrations increase slowly over time until an equilibrium point is reached. The model results were therefore averaged to give, per radionuclide, annually averaged values at 1-year, 5-years, 10-years, 30-years and 60-years.

5 Biota dose assessment for Nuclear Technology (NUK)

The biota dose rate assessments for discharges at the proposed annual discharge limits from the NUK division are discussed in this section. The assessment is focused on routine operational discharges and the resulting annually averaged activity concentrations in the environment. The Ecolego modelling has also considered short-term variations in environmental activity concentrations associated with an accidental gaseous discharge at the annual discharge limit in a single day. The resulting annually averaged activity concentrations associated with this accidental scenario are either similar (longer-lived radionuclides) or less (shorter-lived radionuclides) than compared to routine operational releases. The resulting biota dose rates are therefore either similar or lower and have therefore not been evaluated further.

5.1 Input data from Ecolego

Input data to the ERICA biota dose assessment have been derived on the basis of annual averages of Ecolego-modelled radionuclide activity concentrations in environmental media (air and soil or water and sediment). As discussed in Section 4.3, ERICA automatically calculates dose rates for any short-lived radionuclides (half-life less than 10 days) in decay series (where those series are included by default), based on the activity concentration of the parent radionuclide and assuming secular equilibrium across the decay chain. As such, only activity concentration input data relating to the parent radionuclide in decay series are presented. For discharges from NUK, this applies to Th-228 (decay chain products of Bi-212, Pb-212, Po-212, Po-216, Ra-224 and Tl-208) and Sr-90 (decay product Y-90). Whilst Rn-220 is also a short-lived radionuclide in the Th-228 decay chain, ERICA requires this radionuclide to be assessed independently of the decay series.

5.1.1 Discharges to atmosphere

Modelled annually averaged activity concentrations in air and soil that were used as input to the biota dose assessment for NUK are presented below.

Activity concentrations in air used in the biota dose assessment are shown in Table 5-1.

***Table 5-1:** Radionuclide activity concentration results for air - NUK*

Radionuclide	Activity concentration in air (Bq/m^3) – all years
H-3	5.53E+00
Rn-220	1.38E-02
Rn-222	2.76E-03

Activity concentrations in topsoil used in the biota dose assessment are shown in Table 5-2.

Table 5-2: *Radionuclide activity concentration results for topsoil - NUK*

Radionuclide	Activity concentration in topsoil (Bq/kg)				
	1-year	5-years	10-years	30-years	60-years
Ac-227	1.37E-04	1.16E-03	2.24E-03	5.06E-03	6.82E-03
Bi-211	1.09E-04	1.13E-03	2.22E-03	5.05E-03	6.81E-03
Br-82	1.60E-03	1.62E-03	1.62E-03	1.61E-03	1.61E-03
Cs-134	1.24E-03	6.43E-03	7.89E-03	8.22E-03	8.22E-03
Cs-135	1.39E-04	1.24E-03	2.60E-03	7.76E-03	1.48E-02
Cs-137	4.14E-03	3.55E-02	7.02E-02	1.70E-01	2.48E-01
Eu-152	6.81E-04	5.55E-03	1.03E-02	2.03E-02	2.43E-02
Eu-154	1.35E-03	1.04E-02	1.82E-02	3.02E-02	3.27E-02
Gd-153	9.89E-05	2.61E-04	2.64E-04	2.64E-04	2.64E-04
Hg-203	4.02E-07	5.13E-07	5.13E-07	5.13E-07	5.13E-07
Pb-211	1.09E-04	1.13E-03	2.22E-03	5.05E-03	6.81E-03
Po-215	1.09E-04	1.13E-03	2.22E-03	5.05E-03	6.81E-03
Ra-223	1.09E-04	1.13E-03	2.22E-03	5.04E-03	6.81E-03
Ra-228	1.33E-07	9.60E-07	1.55E-06	2.18E-06	2.24E-06
Sr-90	4.11E-03	3.48E-02	6.76E-02	1.55E-01	2.12E-01
Tb-160	5.54E-05	7.96E-05	7.96E-05	7.96E-05	7.96E-05
Tb-161	7.28E-06	7.59E-06	7.59E-06	7.58E-06	7.58E-06
Tc-99	3.63E-05	8.18E-05	8.24E-05	8.39E-05	8.62E-05
Th-227	1.19E-04	1.14E-03	2.23E-03	5.05E-03	6.81E-03
Th-228	6.13E-05	3.07E-04	3.70E-04	3.82E-04	3.82E-04
Tl-207	1.09E-04	1.13E-03	2.22E-03	5.05E-03	6.81E-03

5.1.2 Discharges to water

Modelled annually averaged activity concentrations in water and sediment that are used as input to the biota dose assessment for NUK are presented below.

Activity concentrations in river water used in the biota dose assessment are shown in Table 5-3.

Table 5-3: Radionuclide activity concentration results for river water - NUK

Radionuclide	Activity concentration in water (Bq/l) – all years
Ac-228	3.10E-05
Ag-108	1.76E-05
Ag-108m	1.76E-05
Ag-110	3.49E-06
Ag-110m	3.49E-06
Bi-211	5.92E-04
Cd-109	1.05E-04
Co-60	1.05E-03
Cs-134	1.05E-04
Cs-137	6.99E-04
H-3	1.76E+01
I-125	1.70E-04
I-131	1.41E-03
Lu-177	1.36E-03
Lu-177m	3.47E-08
Pb-211	5.93E-04
Po-215	6.00E-04
Pu-238	7.01E-07
Pu-239	7.01E-05
Pu-240	7.01E-06
Pu-242	3.51E-07
Ra-223	6.00E-04
Ra-228	3.51E-05
Rh-106	3.49E-05
Rn-219	6.00E-04
Rn-220	2.33E-06
Ru-106	3.49E-05
Sc-46	3.43E-08
Sn-113	3.45E-06
Th-228	8.68E-08
Th-232	3.50E-06
Tl-207	5.91E-04

Activity concentrations in river sediment used in the biota dose assessment are shown in Table 5-4.

Table 5-4: *Radionuclide activity concentration results for river sediment - NUK*

Radionuclide	Activity concentration in sediment (Bq/kg)				
	1-year	5-years	10-years	30-years	60-years
Ac-228	8.31E-05	5.56E-04	1.09E-03	3.03E-03	5.80E-03
Ag-108	4.83E-05	3.41E-04	7.01E-04	2.09E-03	4.02E-03
Ag-108m	4.83E-05	3.41E-04	7.01E-04	2.09E-03	4.02E-03
Ag-110	6.72E-06	1.43E-05	1.44E-05	1.44E-05	1.44E-05
Ag-110m	6.72E-06	1.43E-05	1.44E-05	1.44E-05	1.44E-05
Bi-211	9.91E-05	9.92E-05	9.92E-05	9.92E-05	9.92E-05
Cd-109	1.93E-04	6.03E-04	6.51E-04	6.54E-04	6.54E-04
Co-60	2.24E-03	1.24E-02	1.95E-02	2.65E-02	2.70E-02
Cs-134	1.84E-03	7.48E-03	9.08E-03	9.45E-03	9.45E-03
Cs-137	1.38E-02	9.37E-02	1.83E-01	4.50E-01	6.71E-01
H-3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I-125	6.30E-05	7.05E-05	7.05E-05	7.05E-05	7.05E-05
I-131	8.02E-05	8.03E-05	8.03E-05	8.03E-05	8.03E-05
Lu-177	4.60E-04	4.60E-04	4.61E-04	4.60E-04	4.60E-04
Lu-177m	1.71E-07	2.79E-07	2.79E-07	2.79E-07	2.79E-07
Pb-211	9.91E-05	9.92E-05	9.92E-05	9.92E-05	9.92E-05
Po-215	9.83E-05	9.84E-05	9.84E-05	9.84E-05	9.84E-05
Pu-238	7.26E-06	5.04E-05	1.02E-04	2.79E-04	4.80E-04
Pu-239	7.28E-04	5.13E-03	1.05E-02	3.12E-02	5.96E-02
Pu-240	7.28E-05	5.13E-04	1.05E-03	3.12E-03	5.95E-03
Pu-242	3.64E-06	2.56E-05	5.27E-05	1.56E-04	2.98E-04
Ra-223	9.82E-05	9.84E-05	9.84E-05	9.83E-05	9.84E-05
Ra-228	8.26E-05	5.55E-04	1.09E-03	3.03E-03	5.80E-03
Rh-106	8.73E-05	2.40E-04	2.50E-04	2.50E-04	2.51E-04
Rn-219	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rn-220	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ru-106	8.73E-05	2.40E-04	2.50E-04	2.50E-04	2.51E-04
Sc-46	1.17E-07	1.44E-07	1.44E-07	1.44E-07	1.44E-07
Sn-113	1.56E-05	2.17E-05	2.17E-05	2.17E-05	2.17E-05

Radionuclide	Activity concentration in sediment (Bq/kg)				
	1-year	5-years	10-years	30-years	60-years
Th-228	1.19E-05	2.97E-04	8.11E-04	2.78E-03	5.54E-03
Th-232	6.39E-05	4.53E-04	9.37E-04	2.86E-03	5.70E-03
Tl-207	9.92E-05	9.93E-05	9.93E-05	9.93E-05	9.93E-05

5.2 Addressing radionuclide data gaps

5.2.1 Gaseous discharges

Of the radionuclides in air and soil detailed in Section 5.1.1, Ac-227, Br-82, Gd-153, Hg-203, Tb-160, Tb-161 and Ra-223 and its short-lived progeny Bi-211, Pb-211, Po-215, Rn-219 and Tl-207 are not included by default in ERICA and have therefore been added, with the exception of Rn-219, using the 'add isotope' function[7]. Of these, no element CRs are available for Br-82, Gd-153, Hg-160 and Tb-160/161. Where available, CR data from the WTD [31] have been applied by preference. Remaining data gaps have then been addressed using the following analogue approaches:

- Br-82 data gaps addressed through application of ERICA default CRs for chlorine (Cl), which were higher than the default values for iodine (I).
- Gd-153 and Tb-160/161 data gaps addressed through application of CRs for europium (Eu) as a similar lanthanide.
- Hg-160 data gaps addressed by assigning the highest transitional element CR from ERICA default values.

The CRs applied and their source are detailed in Table 5-5 (note that user-defined representative species have CRs assigned as detailed in Table 4-3).

[7] At the current time, dose rates resulting from radon gas associated with decay series in soils are not calculated within ERICA.

Table 5-5: *Terrestrial reference organism CRs for non-default radionuclides*

Element	Reference organism	Value	Data source/justification
Br	Amphibian	7.00E+00	ERICA default for Cl (higher CR than I)
	Annelid	2.01E-01	ERICA default for Cl (higher CR than I)
	Arthropod - detritivorous	3.04E-01	ERICA default for Cl (higher CR than I)
	Bird	7.00E+00	ERICA default for Cl (higher CR than I)
	Flying insects	2.54E-01	ERICA default for Cl (higher CR than I)
	Grasses & Herbs	7.34E-01	WTD
	Lichen & Bryophytes	1.02E+00	WTD
	Mammal - large	7.00E+00	ERICA default for Cl (higher CR than I)
	Mammal - small-burrowing	7.00E+00	ERICA default for Cl (higher CR than I)
	Mollusc - gastropod	1.97E-01	ERICA default for Cl (higher CR than I)
	Reptile	7.00E+00	ERICA default for Cl (higher CR than I)
	Shrub	1.59E-01	WTD
	Tree	8.50E-02	WTD
Gd	Amphibian	4.34E-02	Eu analogue (similar lanthanide)
	Annelid	7.20E-03	WTD
	Arthropod - detritivorous	1.60E-04	WTD
	Bird	8.60E-03	WTD
	Flying insects	2.06E-03	Eu analogue (similar lanthanide)
	Grasses & Herbs	3.90E-04	WTD
	Lichen & Bryophytes	1.80E-02	WTD
	Mammal - large	1.10E-03	WTD
	Mammal - small-burrowing	1.10E-03	WTD
	Mollusc - gastropod	1.91E-02	Eu analogue (similar lanthanide)
	Reptile	4.34E-02	Eu analogue (similar lanthanide)
	Shrub	3.50E-04	WTD
	Tree	2.20E-03	WTD
Hg	Amphibian	2.98E+00	Zn (mammal) - highest transition element for vertebrate
	Annelid	1.90E+00	WTD
	Arthropod - detritivorous	4.43E+00	Zn (annelid) - highest transition element for invertebrate
	Bird	2.98E+00	Zn (mammal) - highest transition element for vertebrate
	Flying insects	4.43E+00	Zn (annelid) - highest transition element for invert
	Grasses & Herbs	1.10E-02	WTD
	Lichen & Bryophytes	6.87E-01	Highest transitional metal for same organism
	Mammal - large	2.98E+00	Highest transitional metal for same organism

Element	Reference organism	Value	Data source/justification
	Mammal - small-burrowing	2.98E+00	Highest transitional metal for same organism
	Mollusc - gastropod	4.43E+00	Zn (annelid) - highest transition element for invertebrate
	Reptile	2.98E+00	Zn (mammal) - highest transition element for vertebrate
	Shrub	4.56E+00	Assumes Shrub Mn (Highest transition element)
	Tree	4.56E+00	Assumes Shrub Mn (Highest transition element)
Tb	Amphibian	4.34E-02	Eu analogue (similar lanthanide)
	Annelid	7.11E-03	WTD
	Arthropod - detritivorous	5.45E-04	WTD
	Bird	4.00E-02	Eu analogue (similar lanthanide)
	Flying insects	2.06E-03	Eu analogue (similar lanthanide)
	Grasses & Herbs	2.45E-02	WTD
	Lichen & Bryophytes	1.99E-02	WTD
	Mammal - large	2.57E-02	Eu analogue (similar lanthanide)
	Mammal - small-burrowing	2.57E-02	Eu analogue (similar lanthanide)
	Mollusc - gastropod	1.91E-02	Eu analogue (similar lanthanide)
	Reptile	4.34E-02	Eu analogue (similar lanthanide)
	Shrub	2.76E-03	WTD
	Tree	2.20E-03	WTD

5.2.2 Aqueous discharges

For aqueous discharges, the following radionuclides in water and sediment, detailed in Section 5.2, are not included by default in ERICA and were therefore added using the ‘add isotope’ function: Ag-108; Ag-110; Lu-117; Lu-177m; Ra-223 (and its short-lived progeny Bi-211, Pb-211, Po-215, Rn-219 and Tl-207); Sc-46; and Sn-113. Of these, no element CRs are available for Lu-177 and Lu-177m, Sc-46, and Sn-113. Where available, data from the WTD [31] have been applied by preference. Remaining data gaps have then been addressed using the following analogue approaches:

- Lu-177/Lu-177m data gaps addressed through application of CRs for europium (Eu) as a similar lanthanide.
- Sc-46 and Sn-113 data gaps addressed by assigning the highest transitional element CR from ERICA default values.

The CRs applied and their source are detailed in Table 5-6 (note that user-defined representative species have CRs assigned as detailed in Table 4-3).

Table 5-6: *Freshwater reference organism CRs for non-default radionuclides*

Element	Reference organism	Value	Data source/justification
Lu	Amphibian	5.75E+03	Eu analogue (similar lanthanide)
	Benthic fish	4.70E+02	WTD
	Bird	1.59E+03	Eu analogue (similar lanthanide)
	Crustacean	6.17E+01	Eu analogue (similar lanthanide)
	Insect larvae	1.59E+03	Eu analogue (similar lanthanide)
	Mammal	4.79E+03	Eu analogue (similar lanthanide)
	Mollusc - bivalve	2.50E+02	WTD
	Mollusc - gastropod	2.50E+02	WTD
	Pelagic fish	4.70E+02	WTD
	Phytoplankton	6.17E+01	Eu analogue (similar lanthanide)
	Reptile	8.32E+03	Eu analogue (similar lanthanide)
	Vascular plant	2.50E+02	WTD
	Zooplankton	1.59E+03	Eu analogue (similar lanthanide)
Sc	Amphibian	2.00E+03	Highest transitional element
	Benthic fish	3.30E+00	WTD
	Bird	4.80E+00	WTD
	Crustacean	8.34E+03	Highest transitional element
	Insect larvae	3.00E+04	Highest transitional element
	Mammal	8.35E+02	Highest transitional element
	Mollusc - bivalve	4.30E+03	Highest transitional element
	Mollusc - gastropod	4.39E+03	Highest transitional element
	Pelagic fish	3.30E+00	WTD
	Phytoplankton	8.34E+03	Highest transitional element
	Reptile	4.65E+03	Highest transitional element
	Vascular plant	7.70E+01	WTD
	Zooplankton	3.07E+05	Highest transitional element
Sn	Amphibian	2.00E+03	Highest transitional element
	Benthic fish	4.80E+02	WTD
	Bird	3.07E+05	Highest transitional element
	Crustacean	3.90E+02	WTD
	Insect larvae	3.00E+04	Highest transitional element
	Mammal	8.35E+02	Highest transitional element
	Mollusc - bivalve	4.30E+03	Highest transitional element
	Mollusc - gastropod	4.39E+03	Highest transitional element
	Pelagic fish	4.80E+02	WTD

	Phytoplankton	1.90E+02	WTD
	Reptile	4.65E+03	Highest transitional element
	Vascular plant	5.50E+01	WTD
	Zooplankton	3.07E+05	Highest transitional element

5.3 Biota dose assessment results

ERICA calculated terrestrial and aquatic biota dose rate results are discussed below for gaseous and aqueous discharges from NUK. Results presented in this section focus on:

- Total dose rates (across all radionuclides considered) per organism extracted for the 60th year of the Ecolego model assessment and averaged across the year. These are upper bounding values as they allow for radionuclide accumulation in the environment (topsoil and riverbed sediment). These values are plotted relative to the ERICA screening value to determine whether there could be any adverse effect on organisms in the environment.
- Dose rates (across all radionuclides considered) per organism expressed as external and internal exposure for the 1st and 60th year of the assessment to illustrate the effect of radionuclides accumulating in soil and sediment over time on calculated dose rates.
- Key radionuclides contributing to calculated dose rates where radionuclides are presented for every radionuclide that contributes 1% or more to the total dose rate.

Data for all organisms considered, by radionuclide, at the 60th year of the assessment are tabulated in Appendix B.

5.3.1 Gaseous discharges

Dose rates presented below represent upper bounding values as they are for a location close to the site rather than being averaged over areas representative of natural populations of flora and fauna and the identified designated areas discussed in Section 4.1.

5.3.1.1 Total dose rates

Dose rates to terrestrial biota, based on discharges from NUK (inclusive of Ra-223 and its short-lived decay progeny) are shown in Table 5-7 and for the 6th year in Figure 5-1 (please note the logarithmic scale of the y-axis).

Table 5-7: *Total biota dose rates at different years - NUK*

Representative Species	Total biota dose rate (µGy/h)				
	1-year	5-years	10-years	30-years	60-years
Amphibian	7.19E-03	7.29E-03	7.39E-03	7.65E-03	7.82E-03
Annelid	7.74E-03	7.84E-03	7.95E-03	8.22E-03	8.39E-03
Arthropod – detritivorous	1.06E-02	1.07E-02	1.09E-02	1.12E-02	1.14E-02
Bird	6.68E-03	6.73E-03	6.78E-03	6.91E-03	6.99E-03
Flying insects	9.12E-03	9.17E-03	9.23E-03	9.36E-03	9.44E-03
Grasses & Herbs	6.38E-03	6.52E-03	6.65E-03	6.99E-03	7.20E-03
Lichen & Bryophytes	1.36E-02	1.44E-02	1.52E-02	1.73E-02	1.86E-02
Mammal (large burrowing)	6.60E-03	6.70E-03	6.79E-03	7.05E-03	7.22E-03
Mammal (medium)	6.54E-03	6.64E-03	6.73E-03	6.98E-03	7.14E-03
Mammal (semi-aquatic)	6.62E-03	6.71E-03	6.80E-03	7.04E-03	7.21E-03
Mammal – large	6.49E-03	6.60E-03	6.70E-03	6.97E-03	7.16E-03
Mammal - small-burrowing	6.82E-03	6.91E-03	7.01E-03	7.26E-03	7.43E-03
Mollusc – gastropod	8.44E-03	8.49E-03	8.54E-03	8.68E-03	8.76E-03
Reptile	6.73E-03	6.83E-03	6.93E-03	7.19E-03	7.36E-03
Reptile (small)	7.76E-03	7.86E-03	7.96E-03	8.21E-03	8.38E-03
Shrub	6.38E-03	6.52E-03	6.67E-03	7.03E-03	7.27E-03
Tree	6.37E-03	6.41E-03	6.44E-03	6.53E-03	6.59E-03

The results show a slight increase in biota dose rate over time for all organisms and the reason behind this is discussed below.

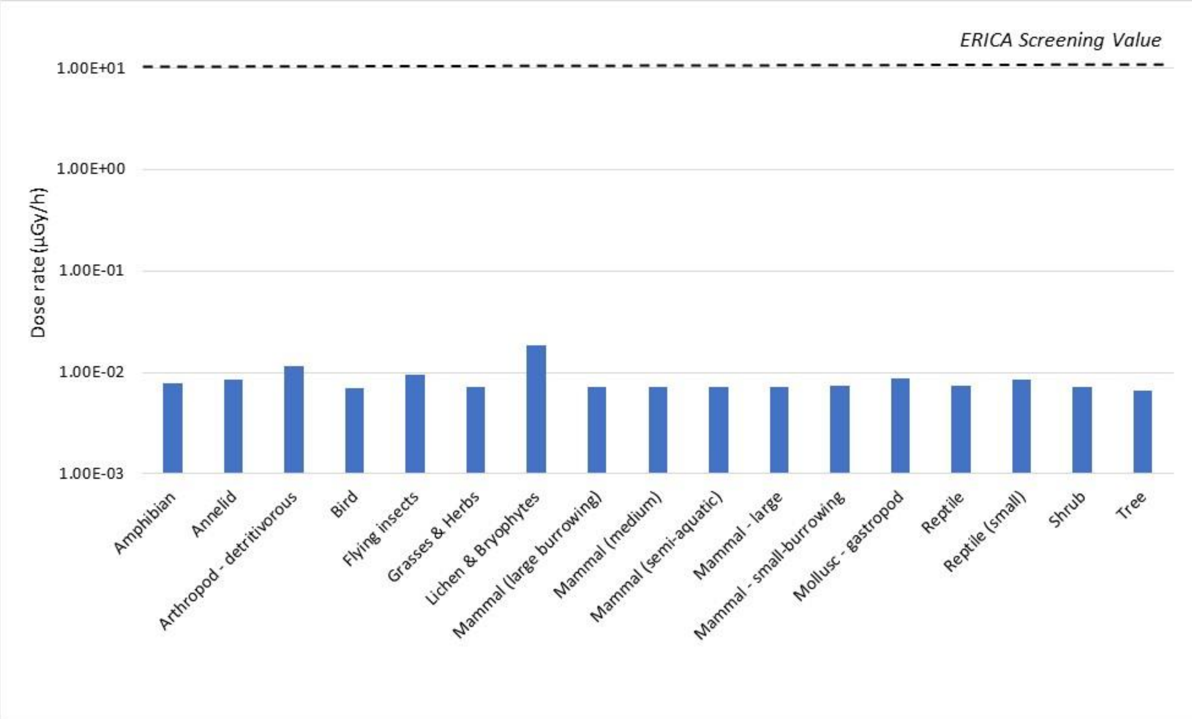

Figure 5-1: *Dose rates to terrestrial biota based on discharges from NUK*

The ERICA calculated dose rates are highest to lichen and bryophyte (1.86E-02 µGy/h) and detritivorous arthropod (1.14E-02 µGy/h). At most, dose rates are over two orders of magnitude lower than the ERICA screening value of 1.00E+01 µGy/h.

5.3.1.2 External and internal dose rates

External and internal dose rates to terrestrial biota, based on discharges from NUK (inclusive of Ra-223 and its short-lived decay progeny) are shown in Figure 5-2 (please note the logarithmic scale of the y-axis). Results are given for the 1st and 60th year of the assessment.

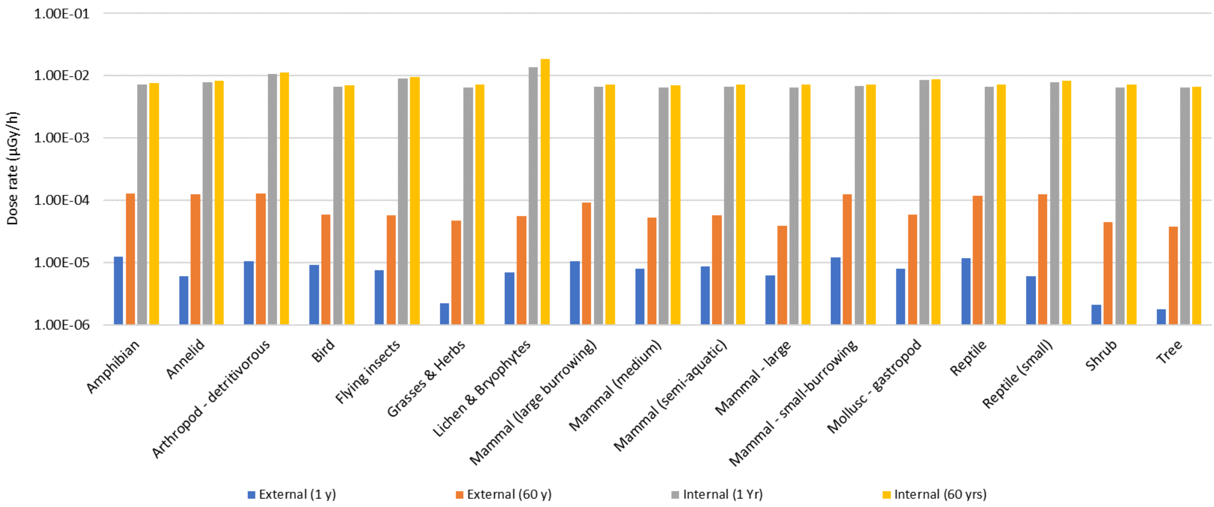

Figure 5-2: *External and internal dose rates to terrestrial biota based on discharges from NUK*

The ERICA calculated dose rates are dominated by internal dose rates that are around two orders of magnitude greater than external dose rates. Internal dose rates are broadly consistent between the 1st and 60th year of the assessment. For terrestrial biota, the internal dose rate is derived from CR values based on the activity concentration in topsoil, except for H-3 and C-14 and noble gases such as radon where the internal dose rate is derived from air concentrations. The primary dose contributor to atmospheric discharges from NUK is H-3 for which air concentrations do not vary over time and, hence, internal dose rates are broadly consistent over time. Where slight increases are observed between internal dose rates at 1 year and 60 years, this relates to the accumulation of Ac-227, Ra-223 and its short-lived daughters, and Sr-90 in topsoil with lower contributions to internal dose rates. The greatest difference in internal dose rates over time is observed for lichen & bryophyte (an increase from 1.36E-02 µGy/h in year 1 to 1.85E-02 µGy/h in year 60). The accumulation of radionuclides in topsoil also gives rise to up to order-of-magnitude differences in external dose rates over time. However, with internal dose rates dominating, the variation in external dose rates has no determinable effect on total dose rates over time.

5.3.1.3 Key radionuclides

Key radionuclides contributing 1% or more to the total dose at year 60, based on discharges from NUK (inclusive of Ra-223 and its short-lived decay progeny) are shown in Figure 5-3.

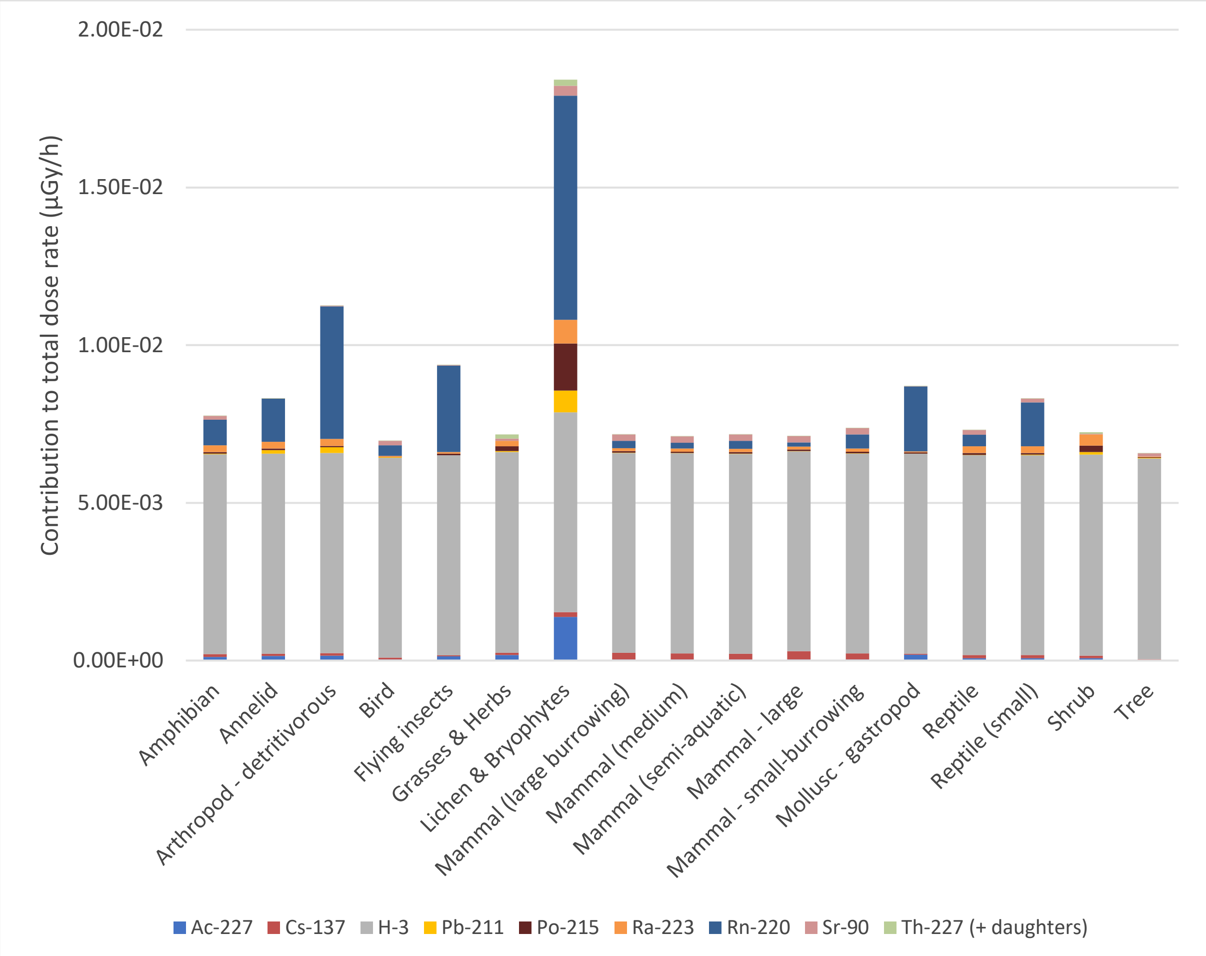

Figure 5-3: *Key radionuclide contribution to dose rates to terrestrial biota based on discharges from NUK*

The ERICA calculated dose rates show that nine radionuclides dominate: Ac-227, Cs-137, H-3, Ra-233 and its short-lived decay products (Po-215, and Pb-211), Rn-220, Sr-90 and Th-227 and its short-lived progeny). For all organisms, with the exception of lichen & bryophyte, the primary dose contributor is H-3. For lichen & bryophyte both Rn-220 and H-3 are key contributors.

Rn-220 is also an important contributor to dose for amphibian, annelid, arthropod – detritivorous, flying insect, lichen & bryophyte, gastropod mollusc and small reptile. Ra-223 and its short-lived progeny are also important contributors, particularly for lichen & bryophyte for which 16% of the total dose rate is attributed to this decay series. Although the dose contribution from Ra-223 and its short-lived progeny will be overestimated due to ECFs not currently being incorporated in dose rate calculations for non-default radionuclides, it is not dominating the dose and has not been assessed further.

5.3.1.4 Summary of dose rates from gaseous discharges

At most, dose rates from gaseous discharges from NUK, are over two orders of magnitude lower than the ERICA screening value of 1.00E+01 µGy/h and are dominated by H-3 in air and, to a lesser extent (with the exception of lichen & bryophyte for which contributions are broadly equal), Rn-220 in air.

5.3.2 Aqueous discharges

5.3.2.1 Total dose rates

Dose rates to aquatic biota, based on discharges from NUK (inclusive of Ra-223 and its short-lived decay progeny) are shown in Table 5-8 and for the 60th year in

Figure 5-4 (please note the logarithmic scale of the y-axis).

Table 5-8: *Total biota dose rates at different years (aquatic biota) - NUK*

Representative Species	Total biota dose rate (µGy/h)				
	1-year	5-years	10-years	30-years	60-years
Amphibian	3.53E-01	3.54E-01	3.54E-01	3.54E-01	3.54E-01
Benthic fish	2.08E-01	2.08E-01	2.08E-01	2.08E-01	2.08E-01
Bird	7.01E-01	7.01E-01	7.02E-01	7.01E-01	7.02E-01

Representative Species	Total biota dose rate (µGy/h)				
	1-year	5-years	10-years	30-years	60-years
Bird (large)	7.01E-01	7.02E-01	7.02E-01	7.02E-01	7.02E-01
Crustacean	6.38E-01	6.38E-01	6.39E-01	6.38E-01	6.39E-01
Crustacean (large)	6.41E-01	6.42E-01	6.42E-01	6.42E-01	6.42E-01
Insect larvae	1.19E+01	1.19E+01	1.19E+01	1.19E+01	1.19E+01
Mammal	1.14E-01	1.14E-01	1.14E-01	1.14E-01	1.14E-01
Mammal (small)	1.14E-01	1.14E-01	1.14E-01	1.14E-01	1.14E-01
Mollusc - bivalve	1.19E+01	1.19E+01	1.19E+01	1.19E+01	1.19E+01
Mollusc - gastropod	7.61E+00	7.61E+00	7.62E+00	7.61E+00	7.62E+00
Pelagic fish	2.07E-01	2.08E-01	2.08E-01	2.07E-01	2.08E-01
Phytoplankton	1.52E-01	1.52E-01	1.52E-01	1.52E-01	1.52E-01
Reptile	4.11E-01	4.12E-01	4.12E-01	4.12E-01	4.12E-01
Vascular plant	1.65E-01	1.65E-01	1.65E-01	1.65E-01	1.65E-01
Zooplankton	1.18E+01	1.19E+01	1.19E+01	1.18E+01	1.19E+01

Based on the values presented to two decimal places, there is no discernible increase in the total dose rate over time. This is discussed below.

***Figure 5-4:** Dose rates to aquatic biota based on discharges from NUK*

The ERICA calculated dose rates are highest to insect larvae (1.19E+01 µGy/h), bivalve mollusc (1.19E+01 µGy/h), gastropod mollusc (7.62E+00 µGy/h), and zooplankton (1.19E+01 µGy/h). These dose rates approach or exceed the ERICA screening value of 1.00E+01 µGy/h and this is discussed further below. For other organisms dose rates are at least an order of magnitude lower than the ERICA screening value of 1.00E+01 µGy/h and below any DCRLs where available.

5.3.2.2 External and internal dose rates

External and internal dose rates to aquatic biota, based on discharges from NUK (inclusive of Ra-223 and its short-lived decay progeny) are shown in

Figure 5-5 (please note the logarithmic scale of the y-axis). Results are given for the 1st and 60th year of the assessment.

Figure 5-5: *External and internal dose rates to aquatic biota based on discharges from NUK*

The ERICA calculated dose rates are dominated by internal dose rates that are several orders of magnitude greater than external dose rates. Internal dose rates are the same between the 1st and 60th year of the assessment. This is consistent with the fact that there is no accumulation of radioactivity in the water column (to which CRs used in the calculation of internal dose rates are applied). External dose rates do increase over time for those organisms that are associated with bed sediment (benthic fish, crustacean, insect larvae, reptile and vascular plant) where dose rates can increase by just over an order of magnitude over 60 years due to build-up of activity in sediment. However, this increase is very small compared to the internal dose rates and as such its effect on the total dose rate is trivial.

5.3.2.3 Key radionuclides

Key radionuclides contributing 1% or more to the total dose at year 60, based on discharges from NUK (inclusive of Ra-223 and its short-lived decay progeny) are shown in Figure 5-6.

Figure 5-6: *Key radionuclide contribution to dose rates to aquatic biota based on discharges from NUK*

The ERICA calculated dose rates show that six radionuclides dominate: Ac-228, Pu-239 and Ra-233 and its short-lived decay products (Po-215, Pb-211, and Bi-211). For insect larvae, molluscs and zooplankton, the two primary dose contributors are Ra-223 and its decay product Po-215. However, due to ECFs not currently being incorporated in dose rate calculations for non-default radionuclides, these dose rates are likely to be significantly over estimated. Dose rates for Ra-223 and its short-lived decay products, for insect larvae have therefore been manually calculated using the dose rate calculations detailed in Section 3.2 and with ECFs calculated according to the ECF equation detailed in Section 3.2.1. The results are shown in Figure 5-7. Results of similar calculations for all non-default radionuclides, again for the most exposed organism, are presented in Appendix B.

Figure 5-7: *Assessment of the effect of the ECF on dose to aquatic insect larvae*

The calculations outlined above suggest that the ERICA predicted dose rate contributions to internal dose may be over-estimated by the following factors:

- Bi-211 – a factor of 1.7E+04
- Pb-211 – a factor of 1.1E+03
- Po-215 – a factor of 1.7E+08
- Ra-223 – a factor of 3.6E+00
- Tl-207 – a factor of 3.3E+03

Hence the contribution from any Ra-223 will be lower by about one-third, that of Pb-211, Bi-211 and Tl-207 will be significantly reduced, and any contribution from Po-215 can effectively be considered to be zero.

5.3.2.4 Key radionuclides (excluding Ra-223 and its decay products)

Due to the ECF issues in the current version of ERICA for non-default radionuclides, the results are re-presented here, where Ra-223 and its short-lived decay progeny have been excluded, in order to illustrate the contributions of other radionuclides to dose rates. The remaining key radionuclides contributing 1% or more to the average annually averaged total dose rates at 60 years, based on discharges from NUK are shown in Figure 5-8.

Figure 5-8: *Key radionuclide contribution to dose rates to aquatic biota based on discharges from NUK (Ra-223 and its short-lived decay progeny excluded)*

If Ra-223 and its short-lived decay progeny are excluded from presentation of the results, Pu-239 and Ra-228, and to a lesser extent Pu-240 and Th-232 are relevant to the total dose rate. However, dose rates are around two orders of magnitude lower with insect larvae still being the most exposed organism. If the ECF adjusted dose rates attributed to Ra-223 and its short-lived decay progeny are included, the total dose rate to insect larvae is 1.48E+00 µGy/h (as compared to 1.19E+01 µGy/h when Ra-223 and its short-lived decay progeny are included without the inclusion of ECFs), i.e., about an order of magnitude lower.

5.3.2.5 Summary of dose rates from aqueous discharges

Dose rates from aqueous discharges from NUK, for the most exposed organisms approach or marginally exceed the ERICA screening value of 1.00E+01 µGy/h. However, considering the overestimations due to the ECF issue for non-default radionuclides, will be about an order of magnitude lower (and below any DCRLs where available).

6 Summary

The radiological assessment for non-human biota associated with aqueous and gaseous emissions of radioactivity from the Kjeller site, has been undertaken using the ERICA assessment methodology and associated tool (version 2.0 – build 2.0.185).

Absorbed internal and external dose rates to a set of freshwater and terrestrial reference organisms have been assessed using tier 2 of the ERICA assessment methodology based on proposed discharge limits from IFE and environmental modelling as described in the Task 2 report [4]. This has included the mapping of reference organisms to local species of fauna and flora and introduction of site-specific representative species where significant differences between interest species and reference organisms were evident.

The assessment is focused on routine operational discharges and the resulting annually averaged activity concentrations in the environment.

6.1 Dose rates to terrestrial biota

The results show an increase in biota dose rate over time for all organisms with the highest dose rates at the 60th year of assessment being calculated for lichen & bryophyte (1.86E-02 μGy/h) and arthropod – detritivorous (1.14E-02 μGy/h). **At most, dose rates are over two orders of magnitude lower than the ERICA screening value of 1.00E+01 μGy/h and well below any DCRLs where available.**

The ERICA calculated dose rates are dominated by internal dose rates that are around two orders of magnitude greater than external dose rates. Internal dose rates are broadly consistent between the 1st and 60th year of the assessment. For terrestrial biota, the internal dose rate is derived from CR values based on the activity concentration in topsoil, except for H-3 and C-14 and noble gases such as radon where the internal dose rate is derived from air concentrations. The primary dose contributor to atmospheric discharges from NUK is H-3 for which air concentrations do not vary over time and, hence, internal dose rates are broadly consistent over time. Rn-220 in air is also an important dose contributor for amphibian, annelid, arthropod – detritivorous, flying insect, lichen & bryophyte, gastropod mollusc and small reptile. Where slight increases are observed between internal dose rates at 1 year and 60 years, this relates to the accumulation of Ac-227, Ra-223 and its short-lived daughters, and Sr-90 in topsoil.

The Ecolego modelling has also considered short-term variations in environmental activity concentrations associated with an accidental gaseous discharge at the annual discharge limit in a single day. The resulting annually averaged activity concentrations associated with this accidental scenario are either similar (longer-lived radionuclides) or less than (shorter-lived radionuclides) compared to routine operational releases. The resulting biota dose rates are therefore either similar or lower and have therefore not been considered further.

It can be concluded that discharges at the proposed limits will have no adverse radiological impact on populations of fauna and flora in the environment, and therefore the ecosystem as a whole.

6.2 Dose rates to aquatic biota

Based on the values presented to two decimal places, there is no discernible increase in the total dose rate over time. At the 60th year of the assessment, the ERICA calculated dose rates are highest for insect larvae (1.19E+01 µGy/h), bivalve mollusc (1.19E+01 µGy/h), gastropod mollusc (7.62E+00 µGy/h), and zooplankton (1.19E+01 µGy/h). These dose rates approach or slightly exceed the ERICA screening value of 1.00E+01 µGy/h. **However, when the ECF issues within the current version of ERICA are considered, the doses are around an order of magnitude lower, around 10% of the ERICA screening value and well below any DCRLs where available.**

The ERICA calculated dose rates are dominated by internal dose rates that are several orders of magnitude greater than external dose rates. Internal dose rates are the same between the 1st and 60th year of the assessment. This is consistent with the fact that there is no accumulation of radioactivity in the water column (to which CRs used in the calculation of internal dose rates are applied). External dose rates do increase over time for those organisms that are associated with bed sediment (benthic fish, crustacean, insect larvae, reptile and vascular plant) where dose rates can increase by just over an order of magnitude over 60 years due to build-up of activity in sediment. However, this increase is very small compared to the internal dose rates and, as such, its effect on the total dose rate is trivial.

The ERICA calculated dose rates show that six radionuclides dominate: Ac-228, Pu-239 and Ra-223 and its short-lived decay products (Po-215, Pb-211, and Bi-211). For insect larvae, molluscs and zooplankton, the two primary dose contributors are Ra-223 and its decay product Po-215. However, due to the ECF issues, these dose rates are likely to be significantly over estimated.

Dose rates for Ra-223 and its short-lived decay products, for insect larvae have therefore been manually calculated. This calculation suggests that ERICA predicted dose rate contributions to internal dose may be over-estimated. When this is accounted for, the contribution from any Ra-223 will be lower by about one-third, that of Pb-211, Bi-211 and Tl-207 will be significantly reduced, and any contribution from Po-215 can effectively be considered to be zero.

If Ra-223 and its short-lived decay progeny are excluded from presentation of the results, Pu-239 and Ra-228, and to a lesser extent Pu-240 and Th-232 are relevant to the total dose rate.

If the ECF adjusted dose rates attributed to Ra-223 and its short-lived decay progeny are included, the total dose rate to insect larvae is 1.48E+00 µGy/h (as compared to 1.19E+01 µGy/h when Ra-223 and its short-lived decay progeny are included without the inclusion of ECFs), i.e., about an order of magnitude lower.

No accident scenario modelling is included in the assessment of discharges to water and dose rates to aquatic biota from planned discharges are considered to be bounding.

It can be concluded that discharges at the proposed limits will have no adverse radiological impact on populations of fauna and flora in the aquatic environment, and therefore the ecosystem as a whole.

7 References

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Appendix

A. ERICA Reference Organism parameterization – NUK

Default ERICA reference organism parameters are presented below. The dimensions and mass of terrestrial reference organisms, along with habitat occupancy assumptions, are presented in Table A-1 and Table A-2 presents the same parameters for freshwater reference organisms. The concentration ratios applied in the assessment are presented in Table A-3 and Table A-4 for terrestrial and freshwater reference organisms, respectively. The ECFs calculated, using the equation set out in Section 3.2.1, for radionuclides that are not included by default within ERICA are presented in Table A-5.

Table A-1: *Dimensions, mass and default occupancy factors for ERICA terrestrial reference organisms.*

Reference organism	Dimensions	Mass	Habitat occupancy
Amphibian	Length - 8 cm Width - 3 cm Height - 3 cm	3.14E-02 kg	In soil
Bird	Length - 30 cm Width - 10 cm Height - 8 cm	1.26E+00 kg	On soil
Annelid	Length - 10 cm Width - 1 cm Height - 1 cm	5.2E-03 kg	In soil
Arthropod - detritivorous	Length - 1.74 cm Width - 0.6 cm Height - 0.3 cm	1.7E-04 kg	In soil
Flying insect	Length - 2 cm Width - 0.75 cm Height - 0.75 cm	5.9E-04 kg	On soil
Grasses & herbs	Length - 5 cm Width - 1 cm Height - 1 cm	2.6E-03 kg	On soil
Lichen & bryophyte	Length - 4 cm Width - 0.23 cm Height - 0.23 cm	1.7E-04 kg	On soil
Mammal - large	Length - 130 cm Width - 60 cm Height - 60 cm	2.45E+02 kg	On soil
Mammal - small burrowing	Length - 20 cm Width - 6 cm Height - 5 cm	3.1E-01 kg	In soil
Gastropod mollusc	Length - 1.9 cm Width - 1.5 cm Height - 0.9 cm	1.4E-03 kg	On soil
Reptile	Length - 116 cm Width - 3.5 cm Height - 3.5 cm	7.4E-01 kg	In soil
Shrub	Length - 5 cm Width - 1 cm Height - 1 cm	2.6E-03 kg	On soil

Reference organism	Dimensions	Mass	Habitat occupancy
Pine tree	Length – 1000 cm Width – 30 cm Height – 30 cm	4.72E+02 kg	On soil

Table A-2: *Dimensions, mass and default occupancy factors for ERICA freshwater reference organisms.*

Reference organism	Dimensions	Mass	Habitat occupancy
Amphibian	Length - 8 cm Width - 3 cm Height - 3 cm	3.14E-02 kg	In water
Bird	Length - 30 cm Width - 10 cm Height - 8 cm	1.26E+00 kg	In water
Mollusc - gastropod	Length - 3 cm Width - 1.5 cm Height - 1.5 cm	3.5E-03 kg	Sediment surface
Benthic fish	Length - 50 cm Width - 8 cm Height - 7 cm	1.47E+00 kg	Sediment surface
Crustacean	Length - 1 cm Width - 0.3 cm Height - 0.1 cm	1.6E-05 kg	Sediment surface
Insect larvae	Length - 1.5 cm Width - 0.15 cm Height - 0.15 cm	1.8E-05 kg	In sediment
Mammal	Length - 33 cm Width - 15 cm Height - 15 cm	3.9E+00 kg	In water
Mollusc - bivalve	Length - 10 cm Width - 4.5 cm Height - 3 cm	7.0E-02 kg	Sediment surface
Pelagic fish	Length - 50 cm Width - 8 cm Height - 6 cm	1.26E+00 kg	In water
Phytoplankton	Length - 0.005 cm Width - 0.005 cm Height - 0.005 cm	1.0E-06 kg	In water
Reptile	Length - 18 cm Width - 12 cm Height - 6 cm	1.0E+00 kg	50% in water 50% in sediment
Vascular plant	Length - 100 cm Width - 0.1 cm Height - 0.2 cm	1.05E-03 kg	Sediment surface
Zooplankton	Length - 0.2 cm Width - 0.14 cm Height - 0.16 cm	2.4E-06 kg	In water

Table A-3: *Concentration ratios (Bq/kg (f.w.) per Bq/kg soil (d.w.) or Bq/m³ air for H, C and noble gases) for ERICA terrestrial reference organisms (CRs for user-defined representative species are assigned as detailed in Table 4 3).*

Element	Amphibian	Annelid	Arthropod - detritivorous	Bird	Flying insects	Grasses & Herbs	Lichen & Bryophytes
Ac	9.82E-02	1.23E-01	1.37E-01	2.83E-02	1.14E-01	1.50E-01	1.20E+00
Bi	1.50E-03	1.90E-02	1.90E-02	5.90E-04	6.76E-02	4.30E-03	2.07E-02
Br	7.00E+00	2.01E-01	3.04E-01	7.00E+00	2.54E-01	7.34E-01	1.02E+00
Cs	4.51E-01	4.15E-02	1.27E-01	5.47E-01	1.28E-01	1.13E+00	3.94E+00
Eu	4.34E-02	7.16E-03	1.91E-02	4.34E-02	2.06E-03	1.39E-02	8.97E-03
Gd	4.34E-02	7.20E-03	1.60E-04	8.60E-03	2.06E-03	3.90E-04	1.80E-02
H	1.50E+02	1.50E+02	1.50E+02	1.50E+02	1.50E+02	1.50E+02	1.50E+02
Hg	2.98E+00	1.90E+00	4.43E+00	2.98E+00	4.43E+00	1.10E-02	6.87E-01
Pb	4.60E-02	4.36E-01	7.02E-01	5.92E-02	1.73E-02	1.15E-01	2.60E+00
Po	8.72E-02	7.63E-02	7.63E-02	9.97E-03	7.63E-02	2.76E-01	2.65E+00
Ra	2.00E-01	2.05E-01	2.05E-01	3.47E-02	5.31E-02	1.66E-01	7.10E-01
Rn	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sr	9.72E-01	6.14E-02	3.01E-01	1.09E+00	2.15E-01	6.64E-01	4.71E+00
Tb	4.34E-02	7.11E-03	5.45E-04	4.00E-02	2.06E-03	2.45E-02	1.99E-02
Tc	3.58E-01	4.43E+00	4.43E+00	1.67E-01	4.43E+00	1.66E+01	1.66E+01
Th	5.70E-04	1.12E-02	1.12E-02	4.69E-04	2.96E-03	1.50E-01	3.77E-01
Tl	1.94E-02	6.55E-02	6.55E-02	7.38E-03	5.24E-02	1.78E-02	1.00E-02
Y	5.50E-05	1.85E-02	1.85E-02	2.80E-04	7.60E-04	1.96E-03	5.05E-02
Ba	2.03E-02	2.15E-02	2.66E-02	2.77E+00	2.66E-02	5.05E-02	1.00E-01

Element	Mammal - large	Mammal - small-burrowing	Mollusc - gastropod	Reptile	Shrub	Tree
Ac	2.74E-02	2.74E-02	1.58E-01	6.60E-02	5.99E-02	9.35E-03
Bi	1.46E-03	1.46E-03	1.90E-02	1.46E-03	5.06E-04	2.74E-02
Br	7.00E+00	7.00E+00	1.97E-01	7.00E+00	1.59E-01	8.50E-02
Cs	2.85E+00	2.85E+00	4.82E-02	6.18E-01	1.82E+00	1.59E-01
Eu	2.57E-02	2.57E-02	1.91E-02	4.34E-02	2.54E-03	2.94E-03
Gd	1.10E-03	1.10E-03	1.91E-02	4.34E-02	3.50E-04	2.20E-03
H	1.50E+02	1.50E+02	1.50E+02	1.50E+02	1.50E+02	1.50E+02
Hg	2.98E+00	2.98E+00	4.43E+00	2.98E+00	4.56E+00	4.56E+00
Pb	3.85E-02	3.85E-02	6.89E-03	4.74E-02	3.29E-01	4.95E-02
Po	8.72E-02	8.72E-02	7.63E-02	9.85E-02	3.50E-01	4.18E-02
Ra	8.93E-02	8.93E-02	2.74E-02	2.00E-01	3.34E-01	1.65E-02
Rn	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sr	1.51E+00	1.51E+00	1.08E-01	1.16E+00	2.07E-01	7.18E-01
Tb	2.57E-02	2.57E-02	1.91E-02	4.34E-02	2.76E-03	2.20E-03
Tc	3.58E-01	3.58E-01	4.43E+00	3.58E-01	1.16E-02	1.16E-02

Element	Mammal - large	Mammal - small-burrowing	Mollusc - gastropod	Reptile	Shrub	Tree
Th	1.11E-03	1.11E-03	1.12E-02	9.55E-04	5.97E-02	1.15E-03
Tl	3.91E-02	3.91E-02	6.55E-02	3.91E-02	1.87E-01	2.30E-02
Y	2.30E-04	2.30E-04	1.85E-02	2.80E-04	1.87E-03	2.81E-03
Ba	5.64E-01	5.64E-01	1.08E-01	8.47E-01	4.77E-01	7.40E-02

Table A-4: *Concentration ratios (Bq/kg(f.w.) per Bq/l) for ERICA freshwater reference organisms (CRs for user-defined representative species are assigned as detailed in Table 4 3).*

Element	Amphibian	Benthic fish	Bird	Crustacean	Insect larvae	Mammal	Mollusc - bivalve
Ac	4.79E+03	1.13E+03	2.91E+03	3.35E+04	3.35E+04	4.79E+03	3.35E+04
Ag	3.00E+02	2.00E+03	3.50E+02	2.07E+04	2.07E+04	3.50E+02	6.36E+03
Bi	1.30E+02	1.30E+02	8.70E+01	1.52E+02	8.21E+01	1.30E+02	6.83E+02
Cd	2.00E+03	1.76E+03	1.89E+03	3.00E+04	3.00E+04	2.00E+03	1.67E+04
Co	2.10E+02	3.68E+02	3.90E+02	1.88E+03	4.69E+03	3.90E+02	4.69E+03
Cs	2.50E+03	3.65E+03	1.88E+03	1.81E+03	1.99E+03	4.00E+03	2.45E+03
H	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
I	3.10E+02	3.10E+02	3.91E+01	8.00E+01	8.00E+01	3.10E+02	8.00E+01
Lu	5.75E+03	4.70E+02	1.59E+03	6.17E+01	1.59E+03	4.79E+03	2.50E+02
Pb	3.56E+01	6.20E+02	4.28E+02	7.92E+03	3.80E+04	4.28E+02	3.80E+04
Po	1.78E+03	1.78E+03	1.78E+03	8.55E+03	1.22E+05	1.78E+03	1.22E+05
Pu	4.79E+03	1.13E+03	2.91E+03	6.03E+02	3.35E+04	4.79E+03	7.11E+03
Ra	2.64E+03	1.04E+03	6.28E+03	2.76E+02	5.23E+04	2.12E-01	5.23E+04
Rh	2.00E+03	8.34E+03	3.35E+03	3.00E+04	3.07E+05	4.30E+03	3.07E+05
Rn	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ru	1.02E+02	1.02E+02	1.02E+02	1.02E+02	1.02E+02	1.02E+02	1.02E+02
Sc	2.00E+03	3.30E+00	4.80E+00	8.34E+03	3.00E+04	8.35E+02	4.30E+03
Sn	2.00E+03	4.80E+02	3.07E+05	3.90E+02	3.00E+04	8.35E+02	4.30E+03
Th	2.20E+01	7.17E+02	5.98E+01	1.74E+04	1.74E+04	4.78E+02	1.74E+04
Tl	1.10E+03	3.99E+03	5.00E+02	9.79E+02	9.79E+02	1.10E+03	9.79E+02
Ba	1.70E+02	4.28E+03	1.85E+03	1.07E+03	3.86E+04	1.85E+03	3.86E+04

Element	Mollusc - gastropod	Pelagic fish	Phytoplankton	Reptile	Vascular plant	Zooplankton
Ac	1.67E+04	1.13E+03	1.19E+04	4.79E+03	4.44E+04	3.35E+04
Ag	6.36E+03	2.00E+03	2.18E+02	3.50E+02	2.18E+02	2.07E+04
Bi	6.83E+02	1.30E+02	3.79E+01	1.30E+02	3.79E+01	6.83E+02
Cd	3.00E+04	1.76E+03	1.83E+03	1.49E+03	3.47E+03	3.00E+04
Co	4.69E+03	3.68E+02	5.64E+02	1.17E+01	9.27E+02	4.69E+03
Cs	1.40E+02	3.65E+03	1.64E+02	4.00E+03	3.42E+02	8.52E+01
H	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
I	1.02E+02	3.10E+02	5.29E+01	3.10E+02	5.29E+01	8.00E+01

Lu	2.50E+02	4.70E+02	6.17E+01	8.32E+03	2.50E+02	1.59E+03
Pb	3.80E+04	6.20E+02	1.59E+03	3.75E+02	4.73E+02	3.80E+04
Po	3.57E+04	1.78E+03	1.21E+03	2.77E+03	1.21E+03	1.22E+05
Pu	3.18E+03	8.97E+02	2.05E+03	4.79E+03	1.45E+03	4.85E+02
Ra	5.23E+04	1.04E+03	5.17E+02	2.64E+03	8.74E+02	5.23E+04
Rh	3.07E+05	8.34E+03	4.65E+03	2.31E+04	4.78E+03	3.07E+05
Rn	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ru	1.02E+02	1.02E+02	9.61E+02	1.02E+02	9.61E+02	1.02E+02
Sc	4.39E+03	3.30E+00	8.34E+03	4.65E+03	7.70E+01	3.07E+05
Sn	4.39E+03	4.80E+02	1.90E+02	4.65E+03	5.50E+01	3.07E+05
Th	1.74E+04	7.17E+02	1.19E+04	4.78E+02	4.44E+04	1.74E+04
Tl	9.79E+02	3.99E+03	8.61E+02	1.10E+03	1.49E+04	9.79E+02
Ba	3.86E+04	4.28E+03	5.02E+01	1.41E+02	4.39E+02	3.86E+04

Table A-5: *Equilibrium correction factors*

Radionuclide	Animals	Plants
Bi-211	4.95E-05	1.49E-04
Pb-211	8.35E-04	2.50E-03
Po-215	6.87E-10	2.06E-09
Ra-223	2.76E-01	5.33E-01
Tl-207	1.10E-04	3.31E-04

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B. Dose rate results

B.1 Dose rates for gaseous emissions

Total dose rates for the 60th year, by radionuclide and by organism, for gaseous discharges from NUK are detailed in Table B-6. Internal and external dose rates for the 60th year, by radionuclide and organism, are presented in Table B-2 and Table B-8, respectively.

Table B-6: *Total dose rates (µGy/h) for the 60th year for terrestrial biota from gaseous discharges. Shaded cells represent short-lived radionuclides in the Cs-137 and Th-228 decay series.*

Element	Terrestrial Biota Total Dose Rates at 60 years (µGy/h)								
	Amphibian	Annelid	Arthropod - detritivorous	Bird	Flying insects	Grasses & Herbs	Lichen & Bryophytes	Mammal (large burrowing)	Mammal (medium)
Ac-227	1.15E-04	1.43E-04	1.60E-04	3.32E-05	1.32E-04	1.74E-04	1.39E-03	3.24E-05	3.21E-05
Bi-211	5.60E-07	5.19E-06	5.19E-06	2.26E-07	1.80E-05	1.21E-06	5.55E-06	5.01E-07	4.47E-07
Br-82	3.85E-06	2.29E-06	2.31E-06	4.14E-06	8.63E-07	9.61E-07	9.70E-07	6.62E-06	6.31E-06
Cs-134	7.21E-06	6.87E-06	6.98E-06	3.74E-06	2.90E-06	3.52E-06	5.34E-06	1.18E-05	1.02E-05
Cs-135	3.45E-07	3.16E-08	9.44E-08	4.20E-07	9.61E-08	8.60E-07	2.88E-06	2.19E-06	2.19E-06
Cs-137	9.12E-05	7.64E-05	7.95E-05	5.85E-05	3.77E-05	6.75E-05	1.48E-04	2.10E-04	1.95E-04
Eu-152	1.43E-05	1.44E-05	1.45E-05	5.66E-06	5.16E-06	5.45E-06	4.84E-06	1.04E-05	5.01E-06
Eu-154	2.09E-05	2.10E-05	2.11E-05	9.01E-06	8.02E-06	7.91E-06	7.46E-06	1.52E-05	8.00E-06
Gd-153	6.86E-09	6.57E-09	6.56E-09	3.04E-09	3.28E-09	3.39E-09	3.56E-09	4.13E-09	2.20E-09
H-3	6.34E-03	6.34E-03	6.34E-03	6.34E-03	6.34E-03	6.37E-03	6.34E-03	6.34E-03	6.34E-03
Hg-203	1.55E-10	1.16E-10	1.89E-10	1.48E-10	1.61E-10	2.42E-11	4.38E-11	1.88E-10	1.81E-10
Pb-211	1.27E-05	1.16E-04	1.87E-04	1.60E-05	4.77E-06	3.07E-05	6.90E-04	1.05E-05	1.04E-05
Po-215	4.94E-05	4.33E-05	4.32E-05	5.78E-06	4.30E-05	1.55E-04	1.49E-03	4.93E-05	4.92E-05
Ra-223	2.13E-04	2.18E-04	2.18E-04	3.72E-05	5.67E-05	1.76E-04	7.52E-04	9.53E-05	9.50E-05
Ra-228	1.48E-08	1.51E-08	1.51E-08	2.84E-09	4.03E-09	1.17E-08	4.83E-08	6.98E-09	6.51E-09
Rn-220	8.19E-04	1.37E-03	4.20E-03	3.30E-04	2.74E-03	0.00E+00	7.10E-03	2.34E-04	1.83E-04
Rn-222	1.17E-05	1.78E-05	5.56E-05	5.42E-06	3.66E-05	0.00E+00	9.34E-05	4.06E-06	3.32E-06
Sr-90	1.20E-04	6.73E-06	2.19E-05	1.45E-04	1.97E-05	7.10E-05	3.15E-04	2.04E-04	2.04E-04
Tb-160	4.61E-08	4.61E-08	4.63E-08	1.80E-08	1.65E-08	1.76E-08	1.75E-08	3.35E-08	1.59E-08
Tb-161	9.75E-11	6.28E-11	5.71E-11	5.96E-11	2.45E-11	5.13E-11	4.57E-11	5.77E-11	4.04E-11
Tc-99	1.80E-09	2.22E-08	2.16E-08	8.44E-10	2.19E-08	8.29E-08	7.92E-08	1.81E-09	1.81E-09
Th-227	1.60E-06	6.88E-06	6.89E-06	8.32E-07	2.10E-06	1.27E-04	1.88E-04	1.47E-06	1.06E-06
Th-228	3.13E-07	1.04E-06	1.04E-06	1.40E-07	2.85E-07	1.06E-05	2.58E-05	2.77E-07	1.75E-07
Tl-207	4.40E-08	1.20E-07	9.61E-08	1.74E-08	8.44E-08	3.32E-08	1.55E-08	8.14E-08	7.85E-08
Y-90	4.55E-10	1.32E-07	7.81E-08	2.52E-09	4.33E-09	3.49E-08	1.92E-07	2.10E-09	2.11E-09
Ba-137m	5.36E-10	5.41E-10	5.43E-10	3.59E-09	2.49E-10	2.80E-10	2.67E-10	1.33E-09	1.27E-09
Ac-228	1.07E-10	1.34E-10	1.49E-10	3.11E-11	1.23E-10	4.77E-10	1.29E-09	3.06E-11	3.01E-11
Po-216	1.63E-13	1.42E-13	1.42E-13	1.91E-14	1.41E-13	1.53E-12	4.88E-12	1.62E-13	1.62E-13
Tl-208	2.03E-12	2.18E-12	2.13E-12	8.13E-13	6.99E-13	8.54E-13	4.93E-13	1.71E-12	1.01E-12
Bi-212	7.93E-11	5.13E-10	5.12E-10	3.13E-11	1.68E-09	3.33E-10	5.22E-10	6.73E-11	5.17E-11
Pb-212	1.24E-08	1.13E-07	1.81E-07	1.55E-08	4.60E-09	8.65E-08	6.69E-07	1.03E-08	1.02E-08

Element	Terrestrial Biota Total Dose Rates at 60 years (µGy/h)								
	Amphibian	**Annelid**	**Arthropod - detritivorous**	**Bird**	**Flying insects**	**Grasses & Herbs**	**Lichen & Bryophytes**	**Mammal (large burrowing)**	**Mammal (medium)**
Po-212	1.27E-19	1.11E-19	1.11E-19	1.45E-20	1.11E-19	1.21E-18	3.87E-18	1.27E-19	1.27E-19
Ra-224	1.31E-06	1.34E-06	1.33E-06	2.27E-07	3.46E-07	2.66E-06	4.61E-06	5.85E-07	5.83E-07

Element	Terrestrial Biota Total Dose Rates at 60 years (µGy/h)							
	Mammal (semi-aquatic)	Mammal - large	Mammal - small-burrowing	Mollusc - gastropod	Reptile	Reptile (small)	Shrub	Tree
Ac-227	3.21E-05	3.19E-05	3.27E-05	1.83E-04	7.73E-05	7.74E-05	6.96E-05	1.12E-05
Bi-211	4.55E-07	4.30E-07	5.42E-07	5.10E-06	5.36E-07	5.52E-07	1.97E-07	7.32E-06
Br-82	5.29E-06	1.16E-05	4.53E-06	8.77E-07	4.26E-06	3.47E-06	8.19E-07	7.95E-07
Cs-134	9.11E-06	1.61E-05	1.03E-05	2.88E-06	6.96E-06	7.36E-06	3.97E-06	2.80E-06
Cs-135	2.19E-06	2.19E-06	2.18E-06	3.65E-08	4.74E-07	4.70E-07	1.38E-06	1.22E-07
Cs-137	1.82E-04	2.62E-04	1.92E-04	3.54E-05	9.31E-05	9.67E-05	9.01E-05	3.51E-05
Eu-152	5.47E-06	3.96E-06	1.36E-05	5.37E-06	1.32E-05	1.44E-05	5.12E-06	4.41E-06
Eu-154	8.69E-06	6.36E-06	1.99E-05	8.41E-06	1.93E-05	2.11E-05	7.42E-06	6.39E-06
Gd-153	2.74E-09	1.37E-09	6.05E-09	3.44E-09	6.25E-09	6.94E-09	3.10E-09	2.59E-09
H-3	6.34E-03	6.34E-03	6.34E-03	6.34E-03	6.34E-03	6.34E-03	6.37E-03	6.37E-03
Hg-203	1.64E-10	2.43E-10	1.64E-10	1.64E-10	1.59E-10	1.50E-10	1.65E-10	3.66E-10
Pb-211	1.04E-05	1.04E-05	1.06E-05	2.01E-06	1.30E-05	1.30E-05	8.78E-05	1.33E-05
Po-215	4.92E-05	4.92E-05	4.94E-05	4.30E-05	5.57E-05	5.57E-05	1.97E-04	2.36E-05
Ra-223	9.51E-05	9.49E-05	9.55E-05	2.95E-05	2.13E-04	2.13E-04	3.54E-04	1.78E-05
Ra-228	6.55E-09	6.45E-09	7.25E-09	2.31E-09	1.47E-08	1.48E-08	2.30E-08	1.51E-09
Rn-220	2.60E-04	1.26E-04	4.53E-04	2.06E-03	3.70E-04	1.39E-03	0.00E+00	0.00E+00
Rn-222	4.41E-06	2.37E-06	6.97E-06	2.79E-05	5.88E-06	1.80E-05	0.00E+00	0.00E+00
Sr-90	2.03E-04	2.06E-04	1.97E-04	1.10E-05	1.46E-04	1.27E-04	2.21E-05	9.79E-05
Tb-160	1.73E-08	1.26E-08	4.39E-08	1.71E-08	4.26E-08	4.66E-08	1.64E-08	1.41E-08
Tb-161	4.38E-11	3.59E-11	7.68E-11	4.06E-11	9.14E-11	9.77E-11	2.71E-11	2.13E-11
Tc-99	1.81E-09	1.81E-09	1.81E-09	2.21E-08	1.81E-09	1.79E-09	5.79E-11	5.87E-11
Th-227	1.13E-06	9.07E-07	1.80E-06	6.18E-06	1.68E-06	1.81E-06	5.09E-05	1.42E-06
Th-228	1.82E-07	1.54E-07	3.38E-07	8.51E-07	3.19E-07	3.43E-07	4.28E-06	1.62E-07
Tl-207	7.84E-08	7.82E-08	8.20E-08	1.11E-07	8.08E-08	7.50E-08	3.17E-07	4.72E-08
Y-90	2.09E-09	2.13E-09	2.03E-09	1.21E-07	2.37E-09	2.00E-09	3.34E-08	6.73E-08
Ba-137m	1.10E-09	2.09E-09	1.03E-09	2.96E-10	1.23E-09	1.00E-09	9.72E-10	8.65E-10
Ac-228	3.01E-11	3.01E-11	3.09E-11	1.70E-10	7.25E-11	7.25E-11	1.91E-10	3.04E-11
Po-216	1.62E-13	1.62E-13	1.63E-13	1.41E-13	1.83E-13	1.83E-13	1.94E-12	2.33E-13
Tl-208	1.02E-12	1.08E-12	2.05E-12	8.07E-13	1.98E-12	2.10E-12	2.36E-12	1.34E-12
Bi-212	5.27E-11	4.88E-11	7.66E-11	4.83E-10	7.51E-11	7.88E-11	5.17E-11	2.06E-09
Pb-212	1.02E-08	1.02E-08	1.04E-08	1.93E-09	1.27E-08	1.27E-08	2.48E-07	3.77E-08
Po-212	1.27E-19	1.27E-19	1.27E-19	1.11E-19	1.44E-19	1.44E-19	1.53E-18	1.83E-19
Ra-224	5.83E-07	5.84E-07	5.85E-07	1.79E-07	1.31E-06	1.31E-06	5.35E-06	2.67E-07

Table B-27: *Internal dose rates (µGy/h) for the 60th year for terrestrial biota from gaseous discharges. Shaded cells represent short-lived radionuclides in the Cs-137 and Th-228 decay series.*

Element	Terrestrial Biota Internal Dose Rates at 60 years (µGy/h)								
	Amphibian	Annelid	Arthropod - detritivorous	Bird	Flying insects	Grasses & Herbs	Lichen & Bryophytes	Mammal (large burrowing)	Mammal (medium)
Ac-227	1.13E-04	1.42E-04	1.59E-04	3.27E-05	1.31E-04	1.74E-04	1.39E-03	3.16E-05	3.16E-05
Bi-211	3.97E-07	5.03E-06	5.02E-06	1.56E-07	1.79E-05	1.14E-06	5.48E-06	3.87E-07	3.87E-07
Br-82	1.62E-06	3.50E-08	4.15E-08	3.29E-06	3.85E-08	1.24E-07	1.32E-07	5.03E-06	5.56E-06
Cs-134	4.66E-07	3.52E-08	8.94E-08	9.56E-07	9.83E-08	9.67E-07	2.64E-06	7.10E-06	7.76E-06
Cs-135	3.45E-07	3.16E-08	9.44E-08	4.20E-07	9.61E-08	8.60E-07	2.88E-06	2.19E-06	2.19E-06
Cs-137	1.73E-05	1.46E-06	3.91E-06	2.58E-05	4.24E-06	3.96E-05	1.15E-04	1.59E-04	1.67E-04
Eu-152	1.11E-07	1.52E-08	3.31E-08	1.82E-07	3.94E-09	2.91E-08	1.49E-08	1.51E-07	1.65E-07
Eu-154	2.58E-07	3.75E-08	8.39E-08	3.60E-07	9.92E-09	7.25E-08	3.77E-08	2.74E-07	2.93E-07
Gd-153	4.59E-10	7.17E-11	1.54E-12	1.15E-10	2.01E-11	3.86E-12	1.72E-10	1.77E-11	1.92E-11
H-3	6.34E-03	6.34E-03	6.34E-03	6.34E-03	6.34E-03	6.37E-03	6.34E-03	6.34E-03	6.34E-03
Hg-203	9.94E-11	5.97E-11	1.32E-10	1.23E-10	1.35E-10	3.44E-13	2.00E-11	1.49E-10	1.60E-10
Pb-211	1.23E-05	1.16E-04	1.86E-04	1.58E-05	4.60E-06	3.06E-05	6.90E-04	1.03E-05	1.03E-05
Po-215	4.90E-05	4.29E-05	4.28E-05	5.61E-06	4.29E-05	1.55E-04	1.49E-03	4.90E-05	4.90E-05
Ra-223	2.12E-04	2.17E-04	2.17E-04	3.68E-05	5.62E-05	1.76E-04	7.51E-04	9.46E-05	9.46E-05
Ra-228	1.36E-08	1.39E-08	1.38E-08	2.36E-09	3.59E-09	1.12E-08	4.79E-08	6.08E-09	6.08E-09
Rn-220	8.13E-04	1.37E-03	4.20E-03	3.25E-04	2.73E-03	0.00E+00	7.10E-03	2.29E-04	1.78E-04
Rn-222	1.06E-05	1.78E-05	5.47E-05	4.22E-06	3.56E-05	0.00E+00	9.25E-05	2.98E-06	2.32E-06
Sr-90	1.20E-04	6.73E-06	2.19E-05	1.45E-04	1.97E-05	7.10E-05	3.15E-04	2.04E-04	2.04E-04
Tb-160	6.11E-10	8.98E-11	6.09E-12	7.68E-10	2.45E-11	3.06E-10	2.14E-10	6.29E-10	6.71E-10
Tb-161	4.25E-11	6.82E-12	5.01E-13	4.07E-11	1.94E-12	2.35E-11	1.79E-11	2.69E-11	2.72E-11
Tc-99	1.80E-09	2.22E-08	2.16E-08	8.44E-10	2.19E-08	8.29E-08	7.92E-08	1.81E-09	1.81E-09
Th-227	2.84E-07	5.55E-06	5.55E-06	2.33E-07	1.47E-06	1.27E-04	1.87E-04	5.52E-07	5.52E-07
Th-228	3.89E-08	7.62E-07	7.61E-07	3.20E-08	2.02E-07	1.05E-05	2.57E-05	7.57E-08	7.57E-08
Tl-207	3.56E-08	1.11E-07	8.75E-08	1.41E-08	8.12E-08	3.00E-08	1.24E-08	7.54E-08	7.56E-08
Y-90	4.55E-10	1.32E-07	7.81E-08	2.52E-09	4.33E-09	3.49E-08	1.92E-07	2.10E-09	2.11E-09
Ba-137m	1.44E-11	1.21E-11	1.10E-11	3.36E-09	1.30E-11	8.31E-11	3.78E-11	9.75E-10	1.07E-09
Ac-228	1.06E-10	1.32E-10	1.48E-10	3.05E-11	1.22E-10	4.77E-10	1.29E-09	2.95E-11	2.96E-11
Po-216	1.61E-13	1.41E-13	1.40E-13	1.84E-14	1.41E-13	1.53E-12	4.88E-12	1.61E-13	1.61E-13
Tl-208	7.24E-14	2.04E-13	1.45E-13	3.98E-14	1.40E-13	1.63E-13	2.04E-14	2.74E-13	2.92E-13
Bi-212	3.71E-11	4.70E-10	4.69E-10	1.46E-11	1.67E-09	3.18E-10	5.11E-10	3.63E-11	3.63E-11
Pb-212	1.19E-08	1.12E-07	1.81E-07	1.53E-08	4.45E-09	8.63E-08	6.69E-07	9.97E-09	9.98E-09
Po-212	1.27E-19	1.11E-19	1.11E-19	1.45E-20	1.11E-19	1.21E-18	3.87E-18	1.27E-19	1.27E-19
Ra-224	1.30E-06	1.33E-06	1.33E-06	2.26E-07	3.45E-07	2.66E-06	4.61E-06	5.82E-07	5.82E-07

Element	Terrestrial Biota Internal Dose Rates at 60 years (µGy/h)							
	Mammal (semi-aquatic)	Mammal - large	Mammal - small-burrowing	Mollusc - gastropod	Reptile	Reptile (small)	Shrub	Tree
Ac-227	3.16E-05	3.16E-05	3.16E-05	1.82E-04	7.63E-05	7.62E-05	6.92E-05	1.08E-05
Bi-211	3.87E-07	3.88E-07	3.87E-07	5.03E-06	3.87E-07	3.87E-07	1.34E-07	7.26E-06
Br-82	4.46E-06	1.10E-05	2.41E-06	3.23E-08	2.22E-06	1.22E-06	2.68E-08	1.20E-07
Cs-134	6.40E-06	1.43E-05	3.90E-06	3.93E-08	7.97E-07	5.24E-07	1.56E-06	7.51E-07
Cs-135	2.19E-06	2.19E-06	2.18E-06	3.65E-08	4.74E-07	4.70E-07	1.38E-06	1.22E-07
Cs-137	1.51E-04	2.41E-04	1.21E-04	1.66E-06	2.57E-05	2.17E-05	6.37E-05	1.28E-05
Eu-152	1.37E-07	2.95E-07	8.57E-08	3.87E-08	1.37E-07	9.19E-08	5.29E-09	3.08E-08
Eu-154	2.54E-07	4.81E-07	1.82E-07	9.66E-08	2.95E-07	2.27E-07	1.32E-08	5.07E-08
Gd-153	1.67E-11	2.39E-11	1.31E-11	1.88E-10	5.09E-10	4.32E-10	3.46E-12	4.86E-11
H-3	6.34E-03	6.34E-03	6.34E-03	6.34E-03	6.34E-03	6.34E-03	6.37E-03	6.37E-03
Hg-203	1.40E-10	2.28E-10	1.10E-10	1.37E-10	1.08E-10	9.37E-11	1.42E-10	3.47E-10
Pb-211	1.03E-05	1.03E-05	1.03E-05	1.83E-06	1.26E-05	1.26E-05	8.77E-05	1.32E-05
Po-215	4.90E-05	4.91E-05	4.90E-05	4.29E-05	5.54E-05	5.53E-05	1.97E-04	2.35E-05
Ra-223	9.46E-05	9.47E-05	9.46E-05	2.90E-05	2.12E-04	2.12E-04	3.54E-04	1.75E-05
Ra-228	6.08E-09	6.12E-09	6.06E-09	1.85E-09	1.36E-08	1.36E-08	2.26E-08	1.13E-09
Rn-220	2.54E-04	1.23E-04	4.47E-04	2.06E-03	3.65E-04	1.39E-03	0.00E+00	0.00E+00
Rn-222	3.31E-06	1.60E-06	5.82E-06	2.69E-05	4.75E-06	1.80E-05	0.00E+00	0.00E+00
Sr-90	2.03E-04	2.06E-04	1.97E-04	1.10E-05	1.46E-04	1.27E-04	2.21E-05	9.79E-05
Tb-160	5.84E-10	1.09E-09	4.25E-10	2.36E-10	6.93E-10	5.48E-10	3.45E-11	8.57E-11
Tb-161	2.66E-11	2.82E-11	2.57E-11	1.82E-11	4.33E-11	4.17E-11	2.64E-12	2.42E-12
Tc-99	1.81E-09	1.81E-09	1.81E-09	2.21E-08	1.81E-09	1.79E-09	5.79E-11	5.87E-11
Th-227	5.52E-07	5.52E-07	5.52E-07	5.55E-06	4.75E-07	4.75E-07	5.04E-05	9.73E-07
Th-228	7.57E-08	7.58E-08	7.57E-08	7.62E-07	6.52E-08	6.52E-08	4.19E-06	8.10E-08
Tl-207	7.52E-08	7.61E-08	7.40E-08	1.08E-07	7.32E-08	6.65E-08	3.14E-07	4.47E-08
Y-90	2.09E-09	2.13E-09	2.03E-09	1.21E-07	2.37E-09	2.00E-09	3.34E-08	6.73E-08
Ba-137m	8.80E-10	1.94E-09	5.37E-10	5.75E-11	7.57E-10	4.75E-10	7.86E-10	7.08E-10
Ac-228	2.95E-11	2.97E-11	2.95E-11	1.70E-10	7.11E-11	7.10E-11	1.90E-10	2.99E-11
Po-216	1.61E-13	1.62E-13	1.61E-13	1.41E-13	1.82E-13	1.82E-13	1.93E-12	2.32E-13
Tl-208	2.53E-13	5.03E-13	1.78E-13	1.92E-13	1.70E-13	1.22E-13	1.70E-12	7.76E-13
Bi-212	3.63E-11	3.65E-11	3.62E-11	4.70E-10	3.62E-11	3.62E-11	3.75E-11	2.04E-09
Pb-212	9.97E-09	1.00E-08	9.95E-09	1.78E-09	1.22E-08	1.22E-08	2.47E-07	3.76E-08
Po-212	1.27E-19	1.27E-19	1.27E-19	1.11E-19	1.44E-19	1.44E-19	1.53E-18	1.83E-19
Ra-224	5.81E-07	5.83E-07	5.81E-07	1.78E-07	1.30E-06	1.30E-06	5.35E-06	2.66E-07

Table B-8: *External dose rates (µGy/h) for the 60th year for terrestrial biota from gaseous discharges. Shaded cells represent short-lived radionuclides in the Cs-137 and Th-228 decay series.*

Element	Terrestrial Biota External Dose Rates at 60 years (µGy/h)								
	Amphibian	Annelid	Arthropod - detritivorous	Bird	Flying insects	Grasses & Herbs	Lichen & Bryophytes	Mammal (large burrowing)	Mammal (medium)
Ac-227	1.18E-06	1.19E-06	1.20E-06	5.34E-07	5.64E-07	5.03E-07	5.03E-07	8.22E-07	4.52E-07
Bi-211	1.62E-07	1.65E-07	1.66E-07	6.97E-08	7.34E-08	6.71E-08	6.71E-08	1.13E-07	5.94E-08
Br-82	2.22E-06	2.25E-06	2.27E-06	8.54E-07	8.24E-07	8.37E-07	8.37E-07	1.58E-06	7.54E-07
Cs-134	6.75E-06	6.84E-06	6.89E-06	2.79E-06	2.80E-06	2.55E-06	2.71E-06	4.71E-06	2.43E-06
Cs-135	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs-137	7.40E-05	7.50E-05	7.55E-05	3.28E-05	3.34E-05	2.79E-05	3.26E-05	5.11E-05	2.85E-05
Eu-152	1.42E-05	1.43E-05	1.44E-05	5.48E-06	5.16E-06	5.42E-06	4.83E-06	1.03E-05	4.85E-06
Eu-154	2.07E-05	2.09E-05	2.11E-05	8.65E-06	8.01E-06	7.84E-06	7.42E-06	1.50E-05	7.71E-06
Gd-153	6.40E-09	6.50E-09	6.56E-09	2.93E-09	3.26E-09	3.39E-09	3.39E-09	4.12E-09	2.18E-09
H-3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hg-203	5.59E-11	5.66E-11	5.70E-11	2.46E-11	2.61E-11	2.38E-11	2.38E-11	3.92E-11	2.09E-11
Pb-211	3.88E-07	3.93E-07	3.96E-07	1.69E-07	1.75E-07	1.54E-07	1.54E-07	2.72E-07	1.46E-07
Po-215	3.89E-07	3.94E-07	3.97E-07	1.70E-07	1.75E-07	1.54E-07	1.54E-07	2.72E-07	1.46E-07
Ra-223	9.48E-07	9.60E-07	9.67E-07	4.38E-07	4.60E-07	4.01E-07	4.01E-07	6.66E-07	3.72E-07
Ra-228	1.24E-09	1.26E-09	1.27E-09	4.83E-10	4.42E-10	4.69E-10	4.11E-10	8.98E-10	4.30E-10
Rn-220	5.22E-06	0.00E+00	3.62E-06	5.63E-06	4.14E-06	0.00E+00	3.62E-06	5.17E-06	4.85E-06
Rn-222	1.14E-06	0.00E+00	9.32E-07	1.20E-06	1.01E-06	0.00E+00	9.32E-07	1.08E-06	1.00E-06
Sr-90	2.49E-11	2.58E-11	2.64E-11	3.11E-12	1.17E-11	1.97E-11	1.27E-11	3.32E-12	1.85E-12
Tb-160	4.55E-08	4.60E-08	4.63E-08	1.72E-08	1.64E-08	1.73E-08	1.73E-08	3.29E-08	1.52E-08
Tb-161	5.50E-11	5.60E-11	5.66E-11	1.89E-11	2.25E-11	2.79E-11	2.79E-11	3.08E-11	1.31E-11
Tc-99	1.44E-14	1.46E-14	1.47E-14	6.78E-15	7.47E-15	8.09E-15	7.50E-15	1.01E-14	5.43E-15
Th-227	1.31E-06	1.33E-06	1.34E-06	5.98E-07	6.31E-07	5.62E-07	6.29E-07	9.19E-07	5.06E-07
Th-228	2.75E-07	2.78E-07	2.80E-07	1.08E-07	8.28E-08	9.98E-08	7.22E-08	2.01E-07	9.88E-08
Tl-207	8.37E-09	8.47E-09	8.53E-09	3.24E-09	3.16E-09	3.15E-09	3.15E-09	5.99E-09	2.85E-09
Y-90	2.65E-13	2.75E-13	2.81E-13	3.31E-14	1.24E-13	2.10E-13	1.35E-13	3.54E-14	1.97E-14
Ba-137m	5.21E-10	5.28E-10	5.32E-10	2.31E-10	2.36E-10	1.97E-10	2.30E-10	3.60E-10	2.01E-10
Ac-228	1.49E-12	1.51E-12	1.52E-12	5.81E-13	5.17E-13	5.59E-13	4.77E-13	1.08E-12	5.19E-13
Po-216	1.83E-15	1.85E-15	1.87E-15	7.21E-16	5.51E-16	6.65E-16	4.79E-16	1.34E-15	6.60E-16
Tl-208	1.95E-12	1.98E-12	1.99E-12	7.73E-13	5.58E-13	6.91E-13	4.72E-13	1.44E-12	7.14E-13
Bi-212	4.21E-11	4.26E-11	4.29E-11	1.66E-11	1.23E-11	1.50E-11	1.05E-11	3.09E-11	1.53E-11
Pb-212	4.84E-10	4.90E-10	4.93E-10	1.90E-10	1.46E-10	1.76E-10	1.27E-10	3.54E-10	1.74E-10
Po-212	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ra-224	4.02E-09	4.07E-09	4.10E-09	1.58E-09	1.21E-09	1.46E-09	1.06E-09	2.94E-09	1.45E-09

Element	Terrestrial Biota External Dose Rates at 60 years (µGy/h)							
	Mammal (semi-aquatic)	Mammal - large	Mammal - small-burrowing	Mollusc - gastropod	Reptile	Reptile (small)	Shrub	Tree
Ac-227	5.16E-07	3.17E-07	1.12E-06	5.65E-07	1.07E-06	1.19E-06	4.71E-07	3.99E-07
Bi-211	6.73E-08	4.21E-08	1.55E-07	7.35E-08	1.48E-07	1.65E-07	6.33E-08	5.36E-08
Br-82	8.31E-07	5.67E-07	2.12E-06	8.45E-07	2.04E-06	2.25E-06	7.92E-07	6.75E-07
Cs-134	2.70E-06	1.80E-06	6.42E-06	2.84E-06	6.16E-06	6.84E-06	2.41E-06	2.04E-06
Cs-135	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs-137	3.18E-05	2.09E-05	7.03E-05	3.38E-05	6.74E-05	7.50E-05	2.64E-05	2.23E-05
Eu-152	5.33E-06	3.67E-06	1.35E-05	5.33E-06	1.30E-05	1.43E-05	5.12E-06	4.38E-06
Eu-154	8.44E-06	5.88E-06	1.98E-05	8.31E-06	1.90E-05	2.09E-05	7.41E-06	6.34E-06
Gd-153	2.73E-09	1.35E-09	6.03E-09	3.25E-09	5.74E-09	6.50E-09	3.09E-09	2.54E-09
H-3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hg-203	2.38E-11	1.46E-11	5.32E-11	2.61E-11	5.11E-11	5.66E-11	2.24E-11	1.91E-11
Pb-211	1.64E-07	1.06E-07	3.69E-07	1.76E-07	3.55E-07	3.93E-07	1.46E-07	1.23E-07
Po-215	1.64E-07	1.06E-07	3.70E-07	1.76E-07	3.55E-07	3.94E-07	1.46E-07	1.24E-07
Ra-223	4.23E-07	2.62E-07	9.02E-07	4.61E-07	8.67E-07	9.60E-07	3.78E-07	3.20E-07
Ra-228	4.71E-10	3.28E-10	1.19E-09	4.58E-10	1.15E-09	1.26E-09	4.43E-10	3.79E-10
Rn-220	5.24E-06	3.86E-06	5.37E-06	4.47E-06	5.36E-06	0.00E+00	0.00E+00	0.00E+00
Rn-222	1.10E-06	7.73E-07	1.14E-06	1.06E-06	1.14E-06	0.00E+00	0.00E+00	0.00E+00
Sr-90	2.53E-12	1.22E-12	2.14E-11	1.07E-11	1.87E-11	2.59E-11	8.55E-12	1.78E-12
Tb-160	1.67E-08	1.15E-08	4.35E-08	1.69E-08	4.19E-08	4.60E-08	1.63E-08	1.40E-08
Tb-161	1.72E-11	7.72E-12	5.11E-11	2.24E-11	4.80E-11	5.60E-11	2.44E-11	1.89E-11
Tc-99	6.49E-15	3.46E-15	1.37E-14	7.43E-15	1.32E-14	1.46E-14	7.30E-15	6.04E-15
Th-227	5.78E-07	3.55E-07	1.25E-06	6.32E-07	1.20E-06	1.33E-06	5.26E-07	4.46E-07
Th-228	1.06E-07	7.83E-08	2.63E-07	8.97E-08	2.53E-07	2.78E-07	9.44E-08	8.13E-08
Tl-207	3.15E-09	2.14E-09	7.99E-09	3.23E-09	7.69E-09	8.47E-09	2.97E-09	2.54E-09
Y-90	2.69E-14	1.30E-14	2.28E-13	1.14E-13	1.99E-13	2.75E-13	9.10E-14	1.90E-14
Ba-137m	2.24E-10	1.47E-10	4.95E-10	2.38E-10	4.75E-10	5.29E-10	1.86E-10	1.57E-10
Ac-228	5.67E-13	3.98E-13	1.43E-12	5.40E-13	1.37E-12	1.51E-12	5.28E-13	4.53E-13
Po-216	7.09E-16	5.23E-16	1.75E-15	5.97E-16	1.69E-15	1.85E-15	6.29E-16	5.42E-16
Tl-208	7.62E-13	5.74E-13	1.87E-12	6.15E-13	1.81E-12	1.98E-12	6.55E-13	5.66E-13
Bi-212	1.64E-11	1.23E-11	4.03E-11	1.35E-11	3.89E-11	4.26E-11	1.42E-11	1.22E-11
Pb-212	1.87E-10	1.38E-10	4.63E-10	1.58E-10	4.47E-10	4.90E-10	1.66E-10	1.43E-10
Po-212	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ra-224	1.56E-09	1.15E-09	3.85E-09	1.31E-09	3.71E-09	4.07E-09	1.38E-09	1.19E-09

B.2 Dose rates for aqueous emissions

Total dose rates for the 60th year, by radionuclide and by organism, for aqueous discharges from NUK are detailed in Table B-9. Internal and external dose rates for the 60th year, by radionuclide and organism, are presented in Table B-10 and Table B-11, respectively.

Table B-9: *Total dose rates (μGy/h) for the 60th year for freshwater biota from aqueous discharges. Shaded cells represent short-lived radionuclides in the Cs-137 and Th-228 decay series.*

Radio-nuclide	Freshwater Biota Total Dose Rates at 60 years (μGy/h)							
	Amphibian	Benthic fish	Bird	Bird (large)	Crustacean	Crustacean (large)	Insect larvae	Mammal
Ac-228	7.16E-05	1.89E-05	4.37E-05	4.37E-05	5.02E-04	5.04E-04	5.05E-04	7.17E-05
Ag-108	1.72E-06	1.21E-05	2.11E-06	2.15E-06	4.26E-05	1.21E-04	4.50E-05	2.13E-06
Ag-108m	4.58E-07	7.79E-06	1.14E-06	1.91E-06	1.03E-05	4.06E-05	1.25E-05	1.56E-06
Ag-110	6.13E-07	4.53E-06	7.97E-07	8.17E-07	7.85E-06	4.44E-05	8.31E-06	8.10E-07
Ag-110m	1.13E-07	1.61E-06	2.97E-07	5.13E-07	2.55E-06	9.46E-06	2.60E-06	4.14E-07
Ba-137m	3.43E-10	1.49E-08	6.33E-09	9.65E-09	1.49E-09	3.54E-09	2.74E-08	8.13E-09
Bi-211	3.00E-03	3.00E-03	2.01E-03	2.01E-03	3.50E-03	3.51E-03	1.88E-03	3.00E-03
Bi-212	7.31E-10	1.05E-09	4.90E-10	4.91E-10	1.33E-09	1.37E-09	1.42E-09	7.33E-10
Cd-109	1.17E-05	1.12E-05	1.20E-05	1.24E-05	1.59E-04	1.81E-04	1.59E-04	1.30E-05
Co-60	2.49E-05	1.04E-04	9.70E-05	1.65E-04	1.21E-04	2.90E-04	2.92E-04	1.34E-04
Cs-134	3.30E-05	8.25E-05	4.20E-05	6.42E-05	1.75E-05	3.33E-05	2.33E-05	1.15E-04
Cs-137	2.70E-04	5.74E-04	2.51E-04	3.08E-04	2.48E-04	3.60E-04	3.86E-04	5.98E-04
H-3	1.34E-04	1.34E-04	1.34E-04	1.34E-04	1.34E-04	1.34E-04	1.34E-04	1.34E-04
I-125	1.01E-06	1.28E-06	1.66E-07	1.85E-07	2.17E-07	2.82E-07	2.16E-07	1.40E-06
I-131	1.14E-05	1.34E-05	1.96E-06	2.28E-06	2.26E-06	3.08E-06	2.14E-06	1.52E-05
Lu-177	6.80E-04	5.74E-05	1.95E-04	2.02E-04	6.22E-06	7.38E-06	1.61E-04	5.98E-04
Lu-177m	4.36E-08	4.66E-09	1.57E-08	2.07E-08	4.79E-10	6.14E-10	1.02E-08	5.55E-08
Pb-211	8.26E-04	1.44E-02	9.94E-03	9.94E-03	1.82E-01	1.84E-01	8.76E-01	9.94E-03
Pb-212	2.09E-09	4.01E-08	2.52E-08	2.52E-08	4.67E-07	4.71E-07	2.23E-06	2.52E-08
Po-212	5.89E-19	5.89E-19	5.89E-19	5.89E-19	2.83E-18	2.83E-18	4.05E-17	5.89E-19
Po-215	8.81E-02	8.81E-02	8.81E-02	8.81E-02	4.22E-01	4.24E-01	6.04E+00	8.81E-02
Po-216	7.44E-13	7.59E-13	7.45E-13	7.46E-13	3.59E-12	3.60E-12	5.11E-11	7.45E-13
Pu-238	1.08E-04	2.56E-05	6.58E-05	6.58E-05	1.36E-05	1.36E-05	7.56E-04	1.08E-04
Pu-239	1.01E-02	2.40E-03	6.18E-03	6.18E-03	1.28E-03	1.28E-03	7.10E-02	1.01E-02
Pu-240	1.02E-03	2.40E-04	6.18E-04	6.18E-04	1.28E-04	1.28E-04	7.11E-03	1.02E-03
Pu-242	4.82E-05	1.14E-05	2.93E-05	2.93E-05	6.07E-06	6.07E-06	3.37E-04	4.82E-05
Ra-223	2.46E-01	9.72E-02	5.87E-01	5.87E-01	2.57E-02	2.58E-02	4.87E+00	1.99E-05
Ra-224	3.90E-06	1.57E-06	9.28E-06	9.29E-06	4.53E-07	4.57E-07	7.72E-05	3.15E-10
Ra-228	2.81E-03	1.11E-03	6.70E-03	6.72E-03	2.94E-04	2.96E-04	5.53E-02	2.45E-07
Rh-106	9.42E-09	2.43E-08	6.19E-09	4.96E-09	1.19E-07	4.97E-08	2.19E-07	5.74E-09
Rn-219	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rn-220	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ru-106	2.29E-06	2.64E-06	2.64E-06	2.76E-06	4.99E-07	2.47E-06	6.08E-07	2.71E-06
Sc-46	7.53E-09	1.14E-10	7.03E-11	8.88E-11	1.69E-08	3.77E-08	6.12E-08	8.46E-09
Sn-113	6.67E-07	1.96E-07	1.26E-04	1.51E-04	8.69E-08	1.40E-07	6.66E-06	3.81E-07
Th-228	3.41E-07	1.32E-05	9.27E-07	9.28E-07	2.72E-04	2.73E-04	2.75E-04	7.41E-06
Th-232	1.90E-06	6.20E-05	5.16E-06	5.16E-06	1.50E-03	1.50E-03	1.50E-03	4.13E-05
Tl-207	1.75E-04	6.62E-04	8.30E-05	8.37E-05	6.75E-05	1.59E-04	7.03E-05	1.84E-04
Tl-208	9.33E-13	1.94E-11	6.12E-13	8.40E-13	1.83E-11	2.43E-11	3.63E-11	1.62E-12

Radio-nuclide	Freshwater Biota Total Dose Rates at 60 years (µGy/h)							
	Mammal (small)	Mollusc - bivalve	Mollusc - gastropod	Pelagic fish	Phyto-plankton	Reptile	Vascular plant	Zoo-plankton
Ac-228	7.16E-05	5.03E-04	2.51E-04	1.70E-05	5.20E-04	7.36E-05	1.95E-03	4.99E-04
Ag-108	2.08E-06	3.71E-05	3.37E-05	1.20E-05	2.20E-07	2.15E-06	1.03E-06	2.66E-05
Ag-108m	8.19E-07	1.27E-05	8.58E-06	5.87E-06	7.62E-08	2.70E-06	2.03E-06	6.44E-06
Ag-110	7.74E-07	1.35E-05	1.09E-05	4.51E-06	4.06E-08	7.94E-07	1.69E-07	4.83E-06
Ag-110m	2.09E-07	2.70E-06	1.61E-06	1.51E-06	2.80E-08	2.91E-07	4.59E-08	2.16E-06
Ba-137m	4.95E-09	8.57E-08	6.38E-08	1.37E-08	4.05E-11	1.13E-09	1.96E-09	1.39E-08
Bi-211	3.00E-03	1.57E-02	1.57E-02	3.00E-03	8.69E-04	3.00E-03	8.71E-04	1.57E-02
Bi-212	7.32E-10	4.19E-09	4.21E-09	7.32E-10	6.33E-10	1.05E-09	1.09E-09	3.81E-09
Cd-109	1.23E-05	9.97E-05	1.70E-04	1.11E-05	9.83E-06	9.44E-06	1.91E-05	1.56E-04
Co-60	6.95E-05	6.27E-04	4.05E-04	8.34E-05	2.87E-05	2.06E-05	7.14E-05	2.36E-04
Cs-134	6.99E-05	3.93E-05	5.76E-06	7.58E-05	9.54E-07	8.99E-05	6.91E-06	5.95E-07
Cs-137	4.81E-04	3.77E-04	1.23E-04	4.71E-04	7.94E-06	6.19E-04	1.48E-04	4.86E-06
H-3	1.34E-04	1.34E-04	1.34E-04	1.34E-04	1.35E-04	1.34E-04	1.35E-04	1.34E-04
I-125	1.17E-06	2.76E-07	3.04E-07	1.27E-06	1.85E-07	1.28E-06	1.87E-07	2.17E-07
I-131	1.25E-05	3.11E-06	3.61E-06	1.33E-05	2.53E-06	1.34E-05	2.95E-06	2.11E-06
Lu-177	5.77E-04	2.98E-05	2.91E-05	5.73E-05	5.23E-06	1.02E-03	2.38E-05	1.44E-04
Lu-177m	4.14E-08	2.05E-09	1.86E-09	4.50E-09	3.79E-10	8.07E-08	1.63E-09	9.56E-09
Pb-211	9.94E-03	8.83E-01	8.82E-01	1.44E-02	3.65E-02	8.71E-03	1.09E-02	8.74E-01
Pb-212	2.51E-08	2.23E-06	2.23E-06	3.64E-08	2.70E-07	2.57E-08	8.58E-08	2.21E-06
Po-212	5.89E-19	4.05E-17	1.18E-17	5.89E-19	1.20E-18	9.19E-19	1.20E-18	4.05E-17
Po-215	8.81E-02	6.06E+00	1.77E+00	8.81E-02	5.94E-02	1.37E-01	5.95E-02	6.03E+00
Po-216	7.44E-13	5.12E-11	1.50E-11	7.45E-13	1.51E-12	1.18E-12	1.53E-12	5.10E-11
Pu-238	1.08E-04	1.60E-04	7.17E-05	2.02E-05	4.62E-05	1.08E-04	3.28E-05	1.09E-05
Pu-239	1.01E-02	1.51E-02	6.74E-03	1.90E-03	4.34E-03	1.01E-02	3.08E-03	1.03E-03
Pu-240	1.02E-03	1.51E-03	6.75E-04	1.90E-04	4.34E-04	1.02E-03	3.09E-04	1.03E-04
Pu-242	4.82E-05	7.15E-05	3.20E-05	9.03E-06	2.06E-05	4.82E-05	1.46E-05	4.88E-06
Ra-223	1.99E-05	4.88E+00	4.88E+00	9.72E-02	4.82E-02	2.46E-01	8.15E-02	4.87E+00
Ra-224	3.15E-10	7.73E-05	7.72E-05	1.54E-06	1.88E-06	3.93E-06	3.22E-06	7.70E-05
Ra-228	2.47E-07	5.57E-02	5.56E-02	1.11E-03	5.46E-04	2.81E-03	9.28E-04	5.52E-02
Rh-106	7.55E-09	1.20E-07	1.22E-07	8.12E-09	3.12E-08	2.88E-08	1.03E-07	3.85E-08
Rn-219	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rn-220	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ru-106	2.53E-06	2.42E-06	1.88E-06	2.60E-06	1.95E-06	2.64E-06	7.66E-06	2.78E-07
Sc-46	4.62E-09	1.83E-08	1.29E-08	5.77E-11	1.46E-08	3.34E-08	2.58E-10	5.69E-07
Sn-113	3.11E-07	1.49E-06	1.36E-06	1.92E-07	2.60E-08	1.88E-06	1.37E-08	4.98E-05
Th-228	7.41E-06	2.72E-04	2.72E-04	1.11E-05	1.89E-04	9.51E-06	7.10E-04	2.69E-04
Th-232	4.13E-05	1.50E-03	1.50E-03	6.19E-05	1.02E-03	4.14E-05	3.83E-03	1.50E-03
Tl-207	1.81E-04	1.58E-04	1.46E-04	6.61E-04	3.05E-05	1.82E-04	1.34E-03	4.44E-05
Tl-208	1.14E-12	1.66E-11	1.71E-11	4.65E-12	3.83E-13	1.59E-11	3.53E-11	1.86E-13

***Table B-10:** Internal dose rates (µGy/h) for the 60th year for freshwater biota from aqueous discharges. Shaded cells represent short-lived radionuclides in the Cs-137 and Th-228 decay series.*

Radio-nuclide	Freshwater Biota Total Dose Rates at 60 years (µGy/h)							
	Amphibian	Benthic fish	Bird	Bird (large)	Crustacean	Crustacean (large)	Insect larvae	Mammal
Ac-228	7.16E-05	1.70E-05	4.36E-05	4.37E-05	4.99E-04	5.01E-04	4.99E-04	7.17E-05
Ag-108	1.71E-06	1.21E-05	2.11E-06	2.15E-06	4.21E-05	1.21E-04	4.41E-05	2.13E-06
Ag-108m	4.42E-07	6.17E-06	1.12E-06	1.90E-06	8.40E-06	3.80E-05	8.66E-06	1.54E-06
Ag-110	6.13E-07	4.53E-06	7.97E-07	8.17E-07	7.85E-06	4.44E-05	8.30E-06	8.10E-07
Ag-110m	1.08E-07	1.60E-06	2.92E-07	5.09E-07	2.53E-06	9.44E-06	2.58E-06	4.10E-07
Ba-137m	3.41E-10	1.42E-08	6.33E-09	9.65E-09	6.78E-10	2.46E-09	2.58E-08	8.13E-09
Bi-211	3.00E-03	3.00E-03	2.01E-03	2.01E-03	3.50E-03	3.51E-03	1.88E-03	3.00E-03
Bi-212	7.31E-10	7.32E-10	4.90E-10	4.91E-10	8.52E-10	8.57E-10	4.59E-10	7.33E-10
Cd-109	1.17E-05	1.12E-05	1.20E-05	1.24E-05	1.59E-04	1.81E-04	1.59E-04	1.30E-05
Co-60	2.35E-05	8.65E-05	9.57E-05	1.64E-04	1.00E-04	2.62E-04	2.53E-04	1.33E-04
Cs-134	3.29E-05	7.88E-05	4.19E-05	6.41E-05	1.31E-05	2.73E-05	1.46E-05	1.15E-04
Cs-137	2.70E-04	4.79E-04	2.50E-04	3.08E-04	1.23E-04	2.06E-04	1.38E-04	5.98E-04
H-3	1.34E-04	1.34E-04	1.34E-04	1.34E-04	1.34E-04	1.34E-04	1.34E-04	1.34E-04
I-125	1.01E-06	1.28E-06	1.64E-07	1.84E-07	2.14E-07	2.80E-07	2.14E-07	1.40E-06
I-131	1.11E-05	1.32E-05	1.69E-06	2.06E-06	2.08E-06	2.99E-06	2.12E-06	1.50E-05
Lu-177	6.80E-04	5.74E-05	1.95E-04	2.02E-04	6.18E-06	7.36E-06	1.61E-04	5.98E-04
Lu-177m	4.36E-08	4.58E-09	1.57E-08	2.07E-08	3.86E-10	4.96E-10	1.00E-08	5.55E-08
Pb-211	8.26E-04	1.44E-02	9.94E-03	9.94E-03	1.82E-01	1.84E-01	8.76E-01	9.94E-03
Pb-212	2.09E-09	3.64E-08	2.52E-08	2.52E-08	4.62E-07	4.65E-07	2.22E-06	2.52E-08
Po-212	5.89E-19	5.89E-19	5.89E-19	5.89E-19	2.83E-18	2.83E-18	4.05E-17	5.89E-19
Po-215	8.81E-02	8.81E-02	8.81E-02	8.81E-02	4.22E-01	4.24E-01	6.04E+00	8.81E-02
Po-216	7.44E-13	7.45E-13	7.45E-13	7.46E-13	3.57E-12	3.58E-12	5.10E-11	7.45E-13
Pu-238	1.08E-04	2.56E-05	6.58E-05	6.58E-05	1.36E-05	1.36E-05	7.56E-04	1.08E-04
Pu-239	1.01E-02	2.40E-03	6.18E-03	6.18E-03	1.28E-03	1.28E-03	7.10E-02	1.01E-02
Pu-240	1.02E-03	2.40E-04	6.18E-04	6.18E-04	1.28E-04	1.28E-04	7.11E-03	1.02E-03
Pu-242	4.82E-05	1.14E-05	2.93E-05	2.93E-05	6.07E-06	6.07E-06	3.37E-04	4.82E-05
Ra-223	2.46E-01	9.72E-02	5.87E-01	5.87E-01	2.57E-02	2.58E-02	4.87E+00	1.98E-05
Ra-224	3.90E-06	1.54E-06	9.28E-06	9.29E-06	4.07E-07	4.07E-07	7.71E-05	3.14E-10
Ra-228	2.81E-03	1.11E-03	6.70E-03	6.72E-03	2.92E-04	2.94E-04	5.53E-02	2.27E-07
Rh-106	5.48E-10	2.62E-09	1.06E-09	1.11E-09	1.28E-09	8.73E-09	1.39E-08	1.40E-09
Rn-219	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rn-220	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ru-106	2.28E-06	2.62E-06	2.63E-06	2.75E-06	3.81E-07	2.43E-06	4.02E-07	2.71E-06
Sc-46	7.49E-09	2.37E-11	3.58E-11	5.91E-11	1.68E-08	3.76E-08	6.10E-08	8.43E-09
Sn-113	6.66E-07	1.95E-07	1.26E-04	1.51E-04	8.46E-08	1.37E-07	6.66E-06	3.80E-07
Th-228	3.41E-07	1.11E-05	9.27E-07	9.28E-07	2.69E-04	2.69E-04	2.69E-04	7.41E-06
Th-232	1.90E-06	6.19E-05	5.16E-06	5.16E-06	1.50E-03	1.50E-03	1.50E-03	4.13E-05
Tl-207	1.75E-04	6.62E-04	8.30E-05	8.37E-05	6.75E-05	1.59E-04	7.03E-05	1.84E-04
Tl-208	9.32E-13	4.78E-12	6.11E-13	8.39E-13	2.82E-13	9.14E-13	2.94E-13	1.62E-12

Element	Freshwater Biota Total Dose Rates at 60 years (µGy/h)							
	Mammal (small)	Mollusc - bivalve	Mollusc - gastropod	Pelagic fish	Phyto-plankton	Reptile	Vascular plant	Zoo-plankton
Ac-228	7.16E-05	5.01E-04	2.49E-04	1.70E-05	5.20E-04	7.17E-05	1.95E-03	4.99E-04
Ag-108	2.08E-06	3.70E-05	3.36E-05	1.20E-05	2.14E-07	2.11E-06	6.47E-07	2.65E-05
Ag-108m	8.04E-07	1.09E-05	6.72E-06	5.86E-06	5.92E-08	1.08E-06	1.14E-07	6.43E-06
Ag-110	7.74E-07	1.35E-05	1.09E-05	4.51E-06	3.83E-08	7.94E-07	1.65E-07	4.83E-06
Ag-110m	2.04E-07	2.69E-06	1.59E-06	1.51E-06	2.23E-08	2.79E-07	3.15E-08	2.16E-06
Ba-137m	4.95E-09	8.50E-08	6.30E-08	1.37E-08	3.87E-11	4.67E-10	1.16E-09	1.39E-08
Bi-211	3.00E-03	1.57E-02	1.57E-02	3.00E-03	8.69E-04	3.00E-03	8.71E-04	1.57E-02
Bi-212	7.32E-10	3.84E-09	3.84E-09	7.32E-10	6.33E-10	7.32E-10	6.35E-10	3.81E-09
Cd-109	1.23E-05	9.97E-05	1.70E-04	1.11E-05	9.83E-06	9.44E-06	1.91E-05	1.56E-04
Co-60	6.81E-05	6.08E-04	3.85E-04	8.20E-05	2.71E-05	2.75E-06	5.11E-05	2.34E-04
Cs-134	6.98E-05	3.52E-05	1.55E-06	7.57E-05	8.56E-07	8.62E-05	2.50E-06	4.97E-07
Cs-137	4.81E-04	2.74E-04	1.41E-05	4.71E-04	7.66E-06	5.24E-04	2.37E-05	4.58E-06
H-3	1.34E-04	1.34E-04	1.34E-04	1.34E-04	1.35E-04	1.34E-04	1.35E-04	1.34E-04
I-125	1.17E-06	2.74E-07	3.02E-07	1.26E-06	1.81E-07	1.28E-06	1.84E-07	2.13E-07
I-131	1.22E-05	2.95E-06	3.45E-06	1.30E-05	2.15E-06	1.32E-05	2.76E-06	1.74E-06
Lu-177	5.77E-04	2.97E-05	2.91E-05	5.73E-05	5.17E-06	1.02E-03	2.38E-05	1.44E-04
Lu-177m	4.14E-08	1.97E-09	1.77E-09	4.48E-09	3.58E-10	8.06E-08	1.54E-09	9.54E-09
Pb-211	9.94E-03	8.83E-01	8.82E-01	1.44E-02	3.65E-02	8.71E-03	1.09E-02	8.74E-01
Pb-212	2.51E-08	2.23E-06	2.23E-06	3.64E-08	2.70E-07	2.20E-08	8.05E-08	2.21E-06
Po-212	5.89E-19	4.05E-17	1.18E-17	5.89E-19	1.20E-18	9.19E-19	1.20E-18	4.05E-17
Po-215	8.81E-02	6.06E+00	1.77E+00	8.81E-02	5.94E-02	1.37E-01	5.95E-02	6.03E+00
Po-216	7.44E-13	5.12E-11	1.50E-11	7.45E-13	1.51E-12	1.16E-12	1.51E-12	5.10E-11
Pu-238	1.08E-04	1.60E-04	7.17E-05	2.02E-05	4.62E-05	1.08E-04	3.28E-05	1.09E-05
Pu-239	1.01E-02	1.51E-02	6.74E-03	1.90E-03	4.34E-03	1.01E-02	3.08E-03	1.03E-03
Pu-240	1.02E-03	1.51E-03	6.75E-04	1.90E-04	4.34E-04	1.02E-03	3.09E-04	1.03E-04
Pu-242	4.82E-05	7.15E-05	3.20E-05	9.03E-06	2.06E-05	4.82E-05	1.46E-05	4.88E-06
Ra-223	1.98E-05	4.88E+00	4.88E+00	9.72E-02	4.82E-02	2.46E-01	8.15E-02	4.87E+00
Ra-224	3.14E-10	7.72E-05	7.72E-05	1.54E-06	1.88E-06	3.90E-06	3.18E-06	7.70E-05
Ra-228	2.26E-07	5.57E-02	5.56E-02	1.11E-03	5.46E-04	2.81E-03	9.26E-04	5.52E-02
Rh-106	1.30E-09	8.79E-08	6.70E-08	2.60E-09	2.79E-10	7.26E-09	1.28E-09	8.16E-09
Rn-219	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rn-220	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ru-106	2.52E-06	2.39E-06	1.83E-06	2.60E-06	1.92E-06	2.62E-06	7.56E-06	2.48E-07
Sc-46	4.58E-09	1.82E-08	1.28E-08	2.26E-11	1.46E-08	3.33E-08	1.54E-10	5.69E-07
Sn-113	3.11E-07	1.48E-06	1.36E-06	1.92E-07	2.52E-08	1.88E-06	1.13E-08	4.98E-05
Th-228	7.41E-06	2.69E-04	2.69E-04	1.11E-05	1.89E-04	7.41E-06	7.07E-04	2.69E-04
Th-232	4.13E-05	1.50E-03	1.50E-03	6.19E-05	1.02E-03	4.13E-05	3.83E-03	1.50E-03
Tl-207	1.81E-04	1.58E-04	1.46E-04	6.61E-04	3.04E-05	1.82E-04	1.34E-03	4.42E-05
Tl-208	1.14E-12	8.85E-13	7.05E-13	4.65E-12	3.82E-13	1.31E-12	1.77E-11	1.85E-13

Table B-11: *External dose rates (μGy/h) for the 60th year for freshwater biota from aqueous discharges. Shaded cells represent short-lived radionuclides in the Cs-137 and Th-228 decay series.*

Element	Freshwater Biota Total Dose Rates at 60 years (μGy/h)							
	Amphibian	Benthic fish	Bird	Bird (large)	Crustacean	Crustacean (large)	Insect larvae	Mammal
Ac-228	2.32E-08	1.95E-06	2.05E-08	1.76E-08	2.81E-06	3.16E-06	5.56E-06	1.90E-08
Ag-108	6.21E-10	3.44E-08	2.96E-10	2.07E-10	4.92E-07	8.24E-08	9.58E-07	2.41E-10
Ag-108m	1.57E-08	1.62E-06	1.40E-08	1.18E-08	1.93E-06	2.64E-06	3.84E-06	1.28E-08
Ag-110	3.97E-10	4.39E-10	1.61E-10	1.02E-10	5.27E-09	9.70E-10	8.40E-09	1.23E-10
Ag-110m	5.34E-09	1.24E-08	4.81E-09	4.11E-09	1.44E-08	1.75E-08	2.32E-08	4.43E-09
Ba-137m	1.54E-12	6.65E-10	1.37E-12	1.16E-12	8.17E-10	1.08E-09	1.63E-09	1.26E-12
Bi-211	2.59E-08	1.02E-08	1.74E-08	1.35E-08	6.82E-08	8.44E-09	1.91E-08	1.51E-08
Bi-212	1.11E-14	3.18E-10	9.88E-15	8.64E-15	4.83E-10	5.16E-10	9.61E-10	9.20E-15
Cd-109	1.08E-09	2.00E-09	5.42E-10	3.25E-10	6.11E-09	4.51E-09	1.04E-08	4.04E-10
Co-60	1.47E-06	1.79E-05	1.33E-06	1.15E-06	2.03E-05	2.80E-05	3.91E-05	1.23E-06
Cs-134	9.01E-08	3.72E-06	8.07E-08	6.84E-08	4.40E-06	6.00E-06	8.69E-06	7.40E-08
Cs-137	2.20E-07	9.45E-05	1.95E-07	1.65E-07	1.25E-04	1.54E-04	2.48E-04	1.79E-07
H-3	4.56E-11	3.45E-12	6.72E-12	2.45E-12	2.92E-12	8.75E-14	0.00E+00	5.14E-12
I-125	3.21E-09	1.31E-09	1.79E-09	1.00E-09	2.89E-09	1.59E-09	1.69E-09	1.29E-09
I-131	3.01E-07	1.42E-07	2.66E-07	2.20E-07	1.84E-07	8.58E-08	1.96E-08	2.41E-07
Lu-177	2.74E-08	1.57E-08	2.33E-08	1.86E-08	3.04E-08	1.33E-08	1.50E-08	2.08E-08
Lu-177m	1.92E-11	7.72E-11	1.69E-11	1.38E-11	9.31E-11	1.18E-10	1.65E-10	1.52E-11
Pb-211	5.52E-08	2.28E-08	3.88E-08	3.08E-08	1.32E-07	1.83E-08	3.69E-08	3.42E-08
Pb-212	1.29E-13	3.69E-09	1.15E-13	9.97E-14	5.55E-09	6.01E-09	1.10E-08	1.07E-13
Po-212	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po-215	5.60E-08	2.30E-08	3.93E-08	3.13E-08	1.33E-07	1.84E-08	3.66E-08	3.47E-08
Po-216	4.90E-19	1.40E-14	4.34E-19	3.77E-19	2.10E-14	2.27E-14	4.18E-14	4.03E-19
Pu-238	2.63E-13	3.18E-11	9.26E-14	4.90E-14	2.35E-10	1.02E-10	4.65E-10	6.38E-14
Pu-239	1.34E-11	2.53E-09	5.91E-12	3.66E-12	1.33E-08	6.74E-09	2.63E-08	4.47E-12
Pu-240	2.49E-12	3.78E-10	8.87E-13	4.72E-13	2.75E-09	1.20E-09	5.45E-09	6.14E-13
Pu-242	1.23E-13	2.21E-11	5.15E-14	3.19E-14	1.28E-10	6.12E-11	2.53E-10	3.88E-14
Ra-223	1.21E-07	5.66E-08	9.66E-08	7.78E-08	1.75E-07	4.22E-08	4.82E-08	8.62E-08
Ra-224	1.08E-12	3.07E-08	9.54E-13	8.28E-13	4.61E-08	4.99E-08	9.17E-08	8.86E-13
Ra-228	2.20E-08	1.63E-06	1.95E-08	1.67E-08	2.34E-06	2.65E-06	4.63E-06	1.79E-08
Rh-106	8.87E-09	2.17E-08	5.14E-09	3.85E-09	1.18E-07	4.09E-08	2.06E-07	4.34E-09
Rn-219	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rn-220	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ru-106	8.87E-09	2.17E-08	5.14E-09	3.85E-09	1.18E-07	4.09E-08	2.06E-07	4.35E-09
Sc-46	3.82E-11	9.06E-11	3.45E-11	2.97E-11	1.04E-10	1.28E-10	1.68E-10	3.19E-11
Sn-113	5.34E-10	1.68E-09	4.57E-10	3.74E-10	2.38E-09	2.56E-09	4.07E-09	4.11E-10
Th-228	7.35E-11	2.10E-06	6.51E-11	5.66E-11	3.15E-06	3.41E-06	6.27E-06	6.05E-11
Th-232	1.19E-10	8.61E-08	1.05E-10	8.94E-11	1.25E-07	1.41E-07	2.48E-07	9.64E-11
Tl-207	1.04E-08	2.14E-09	3.70E-09	2.23E-09	5.84E-08	2.78E-09	1.63E-08	2.76E-09
Tl-208	4.99E-16	1.46E-11	4.54E-16	4.00E-16	1.80E-11	2.34E-11	3.60E-11	4.25E-16

Element	Freshwater Biota Total Dose Rates at 60 years (µGy/h)							
	Mammal (small)	Mollusc - bivalve	Mollusc - gastropod	Pelagic fish	Phyto-plankton	Reptile	Vascular plant	Zoo-plankton
Ac-228	2.18E-08	2.14E-06	2.29E-06	2.09E-08	3.20E-08	1.95E-06	2.70E-06	3.14E-08
Ag-108	3.86E-10	5.95E-08	1.22E-07	3.12E-10	5.37E-09	3.54E-08	3.86E-07	5.06E-09
Ag-108m	1.49E-08	1.78E-06	1.86E-06	1.43E-08	1.69E-08	1.62E-06	1.92E-06	1.69E-08
Ag-110	2.24E-10	8.21E-10	1.84E-09	1.83E-10	2.26E-09	4.31E-10	4.30E-09	2.20E-09
Ag-110m	5.09E-09	1.35E-08	1.40E-08	4.90E-09	5.63E-09	1.25E-08	1.44E-08	5.62E-09
Ba-137m	1.46E-12	7.29E-10	7.61E-10	1.40E-12	1.75E-12	6.65E-10	8.03E-10	1.74E-12
Bi-211	2.01E-08	1.37E-08	2.10E-08	1.78E-08	1.52E-07	1.04E-08	5.64E-08	1.42E-07
Bi-212	1.04E-14	3.48E-10	3.78E-10	1.00E-14	1.60E-14	3.18E-10	4.54E-10	1.58E-14
Cd-109	7.49E-10	3.49E-09	4.78E-09	5.84E-10	1.84E-09	2.05E-09	6.19E-09	1.78E-09
Co-60	1.40E-06	1.93E-05	1.99E-05	1.35E-06	1.53E-06	1.79E-05	2.03E-05	1.53E-06
Cs-134	8.57E-08	4.06E-06	4.22E-06	8.23E-08	9.85E-08	3.72E-06	4.40E-06	9.77E-08
Cs-137	2.08E-07	1.04E-04	1.09E-04	1.99E-07	2.82E-07	9.46E-05	1.24E-04	2.75E-07
H-3	2.46E-13	1.39E-11	5.58E-13	6.72E-12	3.28E-09	7.69E-14	1.55E-08	2.31E-09
I-125	2.42E-09	2.09E-09	2.59E-09	1.95E-09	4.12E-09	1.33E-09	2.87E-09	4.10E-09
I-131	2.84E-07	1.56E-07	1.64E-07	2.71E-07	3.79E-07	1.42E-07	1.87E-07	3.67E-07
Lu-177	2.53E-08	1.79E-08	1.96E-08	2.38E-08	6.18E-08	1.58E-08	3.39E-08	5.53E-08
Lu-177m	1.82E-11	8.57E-11	8.93E-11	1.73E-11	2.10E-11	7.75E-11	9.35E-11	2.08E-11
Pb-211	4.42E-08	2.95E-08	4.32E-08	3.98E-08	2.94E-07	2.31E-08	1.10E-07	2.74E-07
Pb-212	1.21E-13	4.05E-09	4.38E-09	1.17E-13	1.85E-13	3.70E-09	5.26E-09	1.82E-13
Po-212	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po-215	4.48E-08	2.99E-08	4.36E-08	4.03E-08	2.98E-07	2.33E-08	1.11E-07	2.78E-07
Po-216	4.60E-19	1.53E-14	1.66E-14	4.42E-19	7.00E-19	1.40E-14	1.99E-14	6.87E-19
Pu-238	1.47E-13	7.44E-11	1.33E-10	9.98E-14	7.31E-13	3.41E-11	2.24E-10	7.07E-13
Pu-239	8.35E-12	4.86E-09	7.93E-09	6.26E-12	3.44E-11	2.64E-09	1.31E-08	3.32E-11
Pu-240	1.40E-12	8.76E-10	1.56E-09	9.55E-13	6.96E-12	4.04E-10	2.64E-09	6.72E-12
Pu-242	7.46E-14	4.42E-11	7.45E-11	5.48E-14	3.20E-13	2.32E-11	1.22E-10	3.10E-13
Ra-223	1.06E-07	6.72E-08	8.27E-08	9.88E-08	3.72E-07	5.71E-08	1.53E-07	3.50E-07
Ra-224	1.01E-12	3.36E-08	3.64E-08	9.71E-13	1.54E-12	3.07E-08	4.37E-08	1.51E-12
Ra-228	2.07E-08	1.79E-06	1.92E-06	1.98E-08	3.02E-08	1.63E-06	2.25E-06	2.96E-08
Rh-106	6.24E-09	3.16E-08	5.54E-08	5.51E-09	3.09E-08	2.15E-08	1.01E-07	3.03E-08
Rn-219	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rn-220	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ru-106	6.25E-09	3.16E-08	5.54E-08	5.51E-09	3.09E-08	2.15E-08	1.01E-07	3.03E-08
Sc-46	3.65E-11	9.83E-11	1.02E-10	3.51E-11	4.02E-11	9.07E-11	1.04E-10	4.01E-11
Sn-113	4.95E-10	1.90E-09	2.04E-09	4.68E-10	7.32E-10	1.69E-09	2.42E-09	7.04E-10
Th-228	6.90E-11	2.30E-06	2.49E-06	6.63E-11	1.05E-10	2.10E-06	2.99E-06	1.03E-10
Th-232	1.11E-10	9.49E-08	1.02E-07	1.07E-10	1.64E-10	8.62E-08	1.20E-07	1.61E-10
Tl-207	5.47E-09	4.80E-09	1.17E-08	3.89E-09	1.35E-07	2.29E-09	4.65E-08	1.25E-07
Tl-208	4.77E-16	1.57E-11	1.64E-11	4.61E-16	5.82E-16	1.46E-11	1.76E-11	5.77E-16