NATIONAL NUCLEAR REGULATOR

For the protection of persons, property and the environment against nuclear damage

REGULATORY GUIDE

SAFETY ASSESSMENT OF RADIATION HAZARDS TO MEMBERS OF THE PUBLIC FROM NORM ACTIVITIES

RG-002

Rev 0

professionalism integrity valuing our people excellence teamwork

UNRESTRICTED

APPROVAL RECORD

	Name	Designation	Signature	Date
Prepared	A Joubert	Principal Specialist: ERP	Please note: The original, signed document is retained by Records Management	
Reviewed	T Pather	Manager: NTWP		
	A Muller	Special Nuclear Projects Coordinator		
	L Mpete	Functional Coordinator: ERP		
	S Pheto	Chief Inspector: NORM		
	P Mohajane	Manager: NORM		
Recommended for Approval by	O Phillips	Senior Manager: SARA		
Approved	T Tselane	Chief Executive Officer (Interim)		

Contributors:
The following persons contributed to the preparation of the document:
P Mampe, Senior Specialist, ERP
P Hinrichsen, Principal Specialist, ERP
W Speelman, Senior Specialist, ERP
J Pule, Senior Specialist, ERP
F Ratshili, Legal Officer

TABLE OF CONTENTS

1 BACKGROUND 5
2 PURPOSE 5
3 SCOPE 6
4 REFERENCES 6
5 TERMS, DEFINITIONS AND ABBREVIATIONS 10
5.1 Terms & Definitions 10
5.2 Abbreviations 13
6 ASSESSMENT METHODOLGY 13
6.1 Overview 13
6.2 Site Description and Characterization 15
6.3 Process Description 16
6.4 Source Term 16
6.4.1 Source term characterization 16
6.4.2 Progeny and Build up in the environment 17
6.4.3 Exposure Pathways 17
6.5 Critical Group 19
6.5.1 Land Use 19
6.5.2 Habitation Study 20
6.5.3 Age Groups 20
6.6 Assessment Criteria 20
6.6.1 Screening Dose Criteria 20
6.6.2 Screening Dose Assessment Criteria 21
6.6.3 Site Specific Assessment 21
6.7 Sampling 21
6.8 Sample Analysis 22
6.8.1 Screening Sample Analysis 22
6.8.2 Nuclide Specific Sample Analysis 23
6.9 Dose Assessment Process 23
6.9.1 Scenario Development 23
6.9.2 Dose Calculations 23
6.9.3 Input Parameters 23
6.9.4 Manual Methods 27

6.9.5 Codes and Software 27
6.9.6 Sensitivity Analysis 28
6.9.7 Uncertainty Analysis 29
6.9.8 Interpretation of results 29
7 SUBMISSIONS TO NNR 29
APPENDIX 1: CRITICAL GROUP CONCEPT 30
APPENDIX 2: SAMPLING AND ANALYSIS 31
APPENDIX 3: DEFAULT VALUES FOR USE IN SCREENING ASSESSMENTS 39
APPENDIX 4: INTERACTION MATRIX 57
APPENDIX 5: SITE WATER BALANCE 62

1 BACKGROUND

Natural resources that are extracted from the ground such as coal, oil, gold, natural gas and other mineral ores contain various amounts of natural radioactivity. When these resources are extracted and processed, their natural state can be modified which may result in the enhancement of the natural radioactivity content originally present.

Such enhancements may be observed in the residues or the waste generated and/or in the products or by-products and are sometimes high enough to pose a risk to both humans and the environment if they are not adequately controlled.

In the operations and activities involving Naturally Occurring Radioactive Material (NORM), it is possible for radioactive material to be released to the environment, affecting members of the public. Radiation exposure to natural sources of radiation arising from the mining and processing of uranium ores as well as those originating from industries dealing with NORM, warrant appropriate regulatory attention to ensure the protection of persons and the environment.

Mining and minerals processing in South Africa involving NORM are authorised by the National Nuclear Regulator (NNR) in accordance with the provisions of the National Nuclear Regulator Act (NNRA). These requirements are further elaborated in the Regulations on Safety Standards and Regulatory Practices (SSRP), which were promulgated in accordance with Section 36 of the NNRA. The SSRP contains the principal radiation protection and nuclear safety requirements and more specifically, requires a prior safety assessment before operations and activities may be performed at NORM facilities. The SSRP also specifies objectives such as an operational safety assessment, controls and limitations on operation, a maintenance and inspection programme, staffing and qualification, radiation protection, etc. South Africa is a member State of the International Atomic Energy Agency (IAEA), therefore South African Legislation and Standards are strongly influenced by IAEA guidance.

The NNR develops regulations, guides and position papers for use by applicants in the preparation of the documentation required for authorisation. Holders and applicants for authorisations are required to perform prior and operational safety assessments to determine the impact on public health and the environment. The Licensing Guide, LG-1032 “Guideline on the Assessment of Radiation Hazards to Members of the Public from Mining and Minerals Processing Facilities” [72] was approved in April 1997 and widely used by applicants and authorisation holders.

2 PURPOSE

The document is a revision of LG-1032 and provides guidelines to holders and prospective holders of NNR authorisations on how to conduct prior and operational public safety assessments for NORM facilities which carry out activities and operations involving radioactive ores and minerals containing uranium, thorium and their progeny.

3 SCOPE

The document applies to all holders and prospective holders of NNR authorizations and facilities which carry out activities and operations involving NORM.

4 REFERENCES

The following references were consulted during the compilation of this document:

[1] Act No. 47, 1999, National Nuclear Regulator Act

[2] Regulations in terms of section 36, of the National Nuclear Regulator Act, 1999 (Act no. 47 of 1999), on Safety Standards and Regulatory practices (GN R388).

[3] Act No. 62, National Environmental Management Amendment Act (2008).

[4] Aldenkamp, F.J., et al, An assessment of a method for *in situ* Radon exhalation measurements, Kernfysisch Versneller Instituut, Zernikelaan 259747 AA Groningen (1990).

[5] Biomovs-II, Technical report no. 6. "Development of a reference biosphere's methodology for radioactive waste disposal" (1996).

[6] Djeffal, S., et al. Radon measurements: Techniques and Calibrations, Radiation Protection. Dosimetry *45(1/4):* 29-32 (1992).

[7] Environmental Measurements Laboratory, Procedures Manual, HASL-300, USDOE, 376 Hudson Street, New York, NY 10014(1990).

[8] Gilmore, G.; Hemingway, J. Practical gamma-ray spectrometry, John Wiley and Sons (1995).

[9] Greenberg et al. Standard methods for the examination of water and wastewater, American Public Health Association, ISBN 0-87553-131-8 (1985).

[10] Measurement of alpha and beta activity in water and sludge samples: Determination of radon-222 and radium-226, The determination of uranium (including general x-ray fluorescent spectrometric analysis), HMSO Publications, ISBN 011751909 (1986).

[11] Principles for establishing limits for the release of radioactive materials into the environment, IAEA Safety Series No 45 (1978).

[12] Regulatory control of radioactive discharges to the environment, IAEA Safety Standards Series No. WS-G-2.3 (2000).

[13] Generic models and parameters for assessing the environmental transfer of radionuclides from routine releases: Exposure of critical groups, IAEA Safety Series No 57 (1982). (Under Revision)

[14] Generic models for use in assessing the impact of discharges of radioactive substances to the environment, IAEA Safety Report Series No. 19 (2001).

[15] Principles for limiting releases of radioactive effluent into the environment, IAEA Safety Series No 77 (1986a).

[16] Derived intervention levels for application in controlling radiation doses to the public in the event of a nuclear accident or radiological emergency: Principles, procedures and data, IAEA Safety Series No 81 (1986b).

[17] Concept and approaches used in assessing individual and collective doses from releases of radioactive effluent, IAEA-TECDOC-460 (1988).

[18] Assessment of occupational exposure due to intakes of radionuclides: safety guide, IAEA Safety Standards Series No. RS-G-1.2 (1999).

[19] The application of the principles for limiting releases of radioactive effluent in the case of the mining and milling of radioactive ores, IAEA. Safety Series No 90 (1989a).

[20] Evaluating the reliability of predictions made using environmental transfer models,

Vienna IAEA Safety Series No 100 (1989b).
[21] Measurement of radionuclides in food and the environment: A guidebook, IAEA Technical Reports Series No 295 (1989c).
[22] Measurement and calculation of radon releases from uranium mill tailings, IAEA Technical Reports Series No 333 (1992a).
[23] Current practices for the management and confinement of uranium mill tailings, IAEA Technical Reports Series No 335 (1992b).
[24] Handbook of parameter values for the prediction of radionuclide transfer in temperate environments, IAEA Technical Reports Series No 364 (1994).
[25] Characterization of radioactively contaminated sites for remediation purposes, IAEA-TECDOC-1017 (1998).
[26] Radiation protection against Radon in workplaces other than mines, IAEA Safety Report Series No. 33 (2003).
[27] Quantifying uncertainty in nuclear analytical measurements IAEA, Vienna IAEA-TECDOC-1401(2004).
[28] Soil sampling for environmental contaminants, IAEA-TECDOC-1415 (2004).
[29] Treatment of liquid effluent from uranium mines and mills, IAEA-TECDOC-1419 (2004).
[30] Occupational radiation protection in the mining and processing of raw materials, Safety Standards Series No. RS-G-1.6 (2004).
[31] Environmental and source monitoring for purposes of radiation protection, Safety Standards Series No. RS-G-1.8 (2005).
[32] Guidebook on environmental impact assessment for in situ leach mining projects, IAEA-TECDOC-1428 (2005).
[33] Assessing the need for radiation protection measures in work involving minerals and raw materials, IAEA Safety Reports Series No. 49 (2006)
[34] Application of the management system for facilities and activities, IAEA Safety Safety Standards Series No. GS-G-3.1 (2006).
[35] Quantification of radionuclide transfer in terrestrial and freshwater environments for radiological assessments, IAEA Tecdoc 1616 (2009).
[36] Best practice in environmental management of uranium mining, IAEA Nuclear Energy Series No. NF-T-1.2 (2009).
[37] Setting authorized limits for radioactive discharges: Practical issues to considerIAEA-TECDOC-1638 (2010).
[38] Handbook of parameter values for the prediction of radionuclide transfer in terrestrial and freshwater environments, IAEA Technical Reports Series No. 472 (2010).
[39] Radiation protection and safety of radiation sources: International Basic Safety Standards: General Safety Requirements, IAEA Safety Standards Series No. GRS Part 3 (Interim) (2011)
[40] Principles of environmental monitoring related to the handling of radioactive materials, Pergammon Press ICRP Publication 7 (1966a).
[41] Recommendations of the International Commission on Radiological Protection, Pergammon Press ICRP Publication 9 (1966b).
[42] Reference Man: anatomical, physiological and metabolic characteristics. Pergammon Press. ICRP Publication 23 (1979).
[43] Principles of monitoring for the radiation protection of the population. Oxford: Pergammon Press: ICRP Publication 43, Annals of the ICRP Vol 15 (1) (1984).
[44] Recommendations of the International Commission on Radiological Protection, Oxford: Pergammon Press, ICRP Publication 60, Annals Of The ICRP 21 (1-3) (1991).
[45] Human respiratory tract model for radiological protection, Oxford: Elsevier Science Ltd, ICRP Publication 66, Annals of the ICRP 24 (1-3) (1994).
[46] Protection against radon-222 at home and work, ICRP Publication 65, Annals of the

ICRP 23(2), Oxford Pergammon Press.
[47] Age dependent doses to members of the public from intake of radionuclides, Part 2, Ingestion dose coefficients. Oxford, Elsevier Science Ltd: ICRP Publication 67, Annals Of The ICRP 23 (3\4).(1993). Age dependent doses to members of the public from intake of radionuclides, Part 3, Ingestion dose coefficients. Oxford, Elsevier Science Ltd, ICRP Publication 69, Annals of the ICRP 25 (1) (1995a).
[48] Age dependent doses to members of the public from intake of radionuclides, Part 4, Inhalation dose coefficients, Oxford Elsevier Science Ltd, ICRP Publication 71, Annals of the ICRP Vol 25 (3-4) (1995b).
[49] Age dependent doses to members of the public from intake of radionuclides, Part 5, Compilation of ingestion and inhalation dose coefficients, Oxford Elsevier Science Ltd, ICRP Publication 72, (1996).
[50] Assessing dose of the representative person for the purpose of radiation protection of the public and the optimisation of radiological protection, broadening the process, Elsevier Ltd, ICRP Publication 101, Part 1 (2006).
[51] Kotrappa, P; et al. Electret ion chamber system for measurement of environmental radon and environmental gamma radiation, Rad Prot Dos. 45(1/4):107-110 (1992).
[52] Lim. T. et al, High resolution alpha particle spectrometry for radium analysis, Applied Radiation. Isotopes. 40(1):63-71 (1989).
[53] McDowell, W.J. Photon/electron-rejecting alpha liquid scintillation spectrometry (PERALS), A Review. Radioactivity and Radiochemistry, 3(2):26-53 (1992).
[54] Radiological assessment: predicting the transport, bioaccumulation and uptake by man of radionuclides released to the environment, NCRP Report No 76. (1984).
[55] Generic environmental impact statement. NUREG-0511 J Vols.1 and 2. (1979a).
[56] Uranium dispersion and dosimetry code (UDAD) NUREG\CR-0553 ANL\ES 72, (1979b).
[57] NRPB, Industrial Uranium Compounds: Exposure Limits and Assessment of Intake and Toxicity after Inhalation, NRPB, W22, N Stadling, A Hodgson, E Ansoborlo, P Berard, G Etherington, T Fell, E Rance, B le Guen, NRPB (2002).
[58] Pakalns, P. Anal Chim Acta 69: 211 (1974).
[59] Radiological Assessments Corporation: Microairdos; Version 2.0 (1989).
[60] RD-004 Requirements for radioactive Waste Management: Mining and Minerals Processing, Revision 0 (2002).
[61] RD-005 Quality Management Requirements for Activities Involving Radioactive Material: Mining and Minerals Processing, Rev 0(2002).
[62] RD-006 Requirements for the Control of Radiation Hazards: Mining and Minerals Processing, Rev 0 (2002).
[63] RD-007 Requirements for the Control over Radioactive Effluent Discharges and Environmental Surveillance: Mining and Minerals Processing, Rev 0 (2002).
[64] RD-008 Requirements for Emergency Preparedness: Mining and Minerals Processing, Rev 0 (2002).
[65] RD-009 Verbal Emergency Communication with the National Nuclear Regulator: Mining and Minerals Processing, Rev 0 (2002).
[66] RD-010 Requirements for Radiation Dose Limitation: Mining and Minerals Processing, Rev 0 (2002).
[67] RD-011 Requirements for Medical Surveillance and Control of Persons Occupationally Exposed to Radiation: Mining and Minerals Processing, Rev 0 (2002).
[68] RD-012 Notification Requirements for Occurrences Mining and Minerals Processing, Rev 0 (2002).
[69] RD-016 Requirements for authorisation submissions involving computer software and evaluation models for safety calculations, Rev. 0 (2006).
[70] RD-026 Decommissioning of Nuclear Facilities, Rev 0 (2008).

[71] Samuelsson, Pettersson, Exhalation of 222Rn from porous materials, CONF831049, Rad. Prot. Oosim. 7:95-100 (1984).
[72] LG-1032 Guideline on the Assessment of Radiation Hazards to Members of the Public from Mining and Minerals Processing Facilities (1997).
[73] Sanchez-Cabeza, J.A Pujol, LI, A rapid method for the simultaneous determination of gross alpha and beta activities in water samples using a low background liquid scintillation counter, Health Phys. 68(5):674-682 (1995).
[74] Somogyi, et al, Measurement of exhalation and diffusion parameters of radon in solids by plastic track detectors, Nuclear Tracks 12 (1-6): 701-704; (1986).
[75] Tschurlovits, Beninson, Statistical characterisation of a critical group, Rad. Prot. Dos. 4(1), pages33-36(1983).
[76] USDOE: GENII, The Hanford environmental radiation dosimetry software system, Report PNL-65845 Vol 1-3 (1988).
[77] Zettwoog, Bernhard, Vauzelle, Measurement of the Radiological Impact of Environmental Radon 222 releases from Heaps of Solid Wastes from the Mineral Industry, IRPA Conference Johannesburg (1995).
[78] Database of the Food and Agriculture Organisation of the United Nations, Food balance sheets (2008)
[79] EPA-402-R-93-081, Federal Guidance Report No. 12, External Exposure to Radionuclides in Air, Water, and Soil, Keith F. Eckerman and Jeffrey C. Ryman, 1993
[80] EPA-600 EPA/600/R-09/052F, Exposure Factor Handbook, 2011
[81] Comparison of the Models and Assumptions used in the DandD 1.0, RESRAD 5.61, and RESRAD-Build 1.50 Computer Codes with Respect to the Residential Farmer and Industrial Occupant Scenarios Provided in NUREG/CR-5512, NUREG/CR-512 Volume 4, US Nuclear Regulatory Commission, 1999
[82] Safety Assessment Methodologies for Near Surface Disposal Facilities, Volume 1 and Volume 2, IAEA, 2004, ISBN 92–0–104004–0.
[83] Report on South African Food Consumption Studies Undertaken Amongst Different Population Groups, 1983 – 2000: Average Intakes of Foods Most Commonly Consumed, JH Nel and NP Steyn
[84] IAEA Safety Glossary, Terminology used in Nuclear Safety and Radiation Protection, 2007

5 TERMS, DEFINITIONS AND ABBREVIATIONS

5.1 Terms & Definitions

Action*:* means the use, possession, production, storage, enrichment, processing, reprocessing, conveying or disposal of, or causing to be conveyed, radioactive material; any action, the performance of which may result in persons accumulating a radiation dose resulting from exposure to ionizing radiation; or any other action involving radioactive material;

Assessment*:* means the process, and the result, of analysing systematically the hazards associated with sources and actions, and associated protection and safety measures, aimed at quantifying performance measures for comparison with criteria;

Authorised action: means an *action* authorised in terms of the National Nuclear Regulator Act, 1999 (Act No. 47 of 1999);

Average member of the critical group*:* means the individual receiving the Average effective dose or equivalent dose (as applicable) in the critical group;

Characterization: means the determination of the nature and activity of radionuclides present in a specified place.

Closure: means administrative and technical actions directed at a on surface storage facility at the end of its operating lifetime e.g. covering of the disposed waste (for a near surface repository) or backfilling and/or sealing (for a geological repository and the passages leading to it) and the termination and completion of activities in any associated structures.

Contamination: means radioactive substances on surfaces, or within solids, liquids or gases (including the human body), where their presence is unintended or undesirable, or the process giving rise to their presence in such places.

Collective dose*:* means an expression for the total radiation dose incurred by a population, defined as the product of the number of individuals exposed to a source and their average radiation dose. The collective dose is expressed in person-sievert (person Sv) (see collective effective dose);

Cradle to grave approach: means an approach in which all the stages in the lifetime of a facility, activity or product are taken into consideration.

Critical group*:* means a group of members of the public which is reasonably homogeneous with respect to its exposure for a given radiation source and given exposure pathway and is typical of individuals receiving the highest effective dose or equivalent dose (as applicable) by the given exposure pathway from the given source;

Dose*:* means the sum of the external and internally committed effective dose integrated over the lifetime appropriate to the identified critical group;

Dose coefficient: means the dose, in sievert (Sv), in relation to the media with which it is expressed, such as surface area (Sv/m^2), volume (Sv/m^3 or Sv/L), mass (Sv/kg), radioactive activity (Sv/Bq), time (Sv/a), etc.

Dose constraint: means a prospective and source-related restriction on the Individual dose arising from the predicted operation of the authorised action which serves exclusively as a bound on the optimisation of radiation protection and nuclear safety:

- to limit the range of options considered in the optimisation process, and
- to restrict the doses via all exposure pathways to the average member of the critical group, in order to ensure that the sum of the doses received by that individual from all controlled sources remains within the dose limit, and which, if found retrospectively to have been exceeded, should not be regarded as an infringement of regulatory requirements but rather as a call for the reassessment of the optimisation of radiation protection.

Dose limit**:** means the value of effective dose or equivalent dose to individuals from actions authorised by a nuclear installation licence, nuclear vessel licence or certificate of registration, that must not be exceeded;

Effective dose*:* means the quantity E expressed in the unit J·kg^{-1}, termed the sievert (Sv), defined as the summation of the tissue equivalent doses, each multiplied by the appropriate tissue weighting factor:

$$E = \sum_T w_T \cdot H_T$$

where H_T is the equivalent dose in tissue T and w_T is the tissue weighting factor for tissue T; from the definition of equivalent dose, it follows that:

$$E = \sum_T w_T \cdot \sum_R w_R \cdot D_{T,R}$$

where w_R is the radiation weighting factor for radiation R and $D_{T,R}$ is the average absorbed dose in the organ or tissue T;

Equivalent dose*:* means the quantity $H_{T,R}$ expressed in the unit J·kg^{-1}, termed the sievert (Sv), defined as:

$$H_{T,R} = D_{T,R} \cdot w_R$$

where $D_{T,R}$ is the absorbed dose delivered by radiation type R averaged over a tissue or organ T and w_R is the radiation weighting factor for radiation type R; when the radiation field is composed of different radiation types with different values of w_R, the equivalent dose is:

$$H_T = \sum_R w_R \cdot D_{T,R}$$

Event*:* means an activity that occurred given rise to an exposure scenario.

Exclusion*:* means exclusion from the scope of regulatory control;

Exemption: means the determination by the regulator that an action need not be subject to some or all aspects of regulatory control on the basis that the exposure (or potential exposure) due to the action is too small to warrant the application of those aspects;

Exposure pathway: means a route by which *radiation* or radionuclides can reach humans and cause *exposure*.

Feature: means the physical properties of an object, such as the morphological properties of soil.

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

Nuclear authorisation*:* means a nuclear installation license, nuclear vessel license, certificate of registration or certificate of exemption;

Operational safety assessment*:* means a safety assessment undertaken during operations;

Prior safety assessment*:* means a safety assessment undertaken prior to commencement of operations;

Process*:* means the sequence of events with a specific point of initiation and a defined end point, e.g. the atmospheric dispersion process refers to the dispersion of gaseous radioactive nuclides from the point of release to the deposition at the receptor.

Public*: means* those individuals living off the site;

Public Safety Assessment: means assessment of all aspects of radiological safety relevant to members of the public from an authorized facility.

Site*:* means authorisation sites as described in the individual nuclear authorisation;

Release*:* means the movement of radioactive material from the site into the environment;

Risk: means (qualitatively expressed) the probability of a specified health effect occurring in a person or group as a result of exposure to radiation or (quantitatively expressed) a multi attribute quantity expressing hazard, danger or chance of harmful or injurious consequences associated with actual or potential exposures relating to quantities such as the probability that specific deleterious consequences may arise and the magnitude and character of such consequences;

Safety assessment*:* means an analysis to evaluate the performance of an overall system and its impact, where the performance measure is radiological impact or some other global measure of impact on safety;

Sensitivity analysis: means a quantitative examination of how the behavior of a system varies with change, usually in the values of the governing parameters.

Source Term*:* means the amount and isotopic composition of material released (or postulated to be released) from a facility.

Uncertainty analysis**:** means an analysis to estimate the uncertainties and error bounds of the quantities involved in, and the results from, the solution of a problem.

Validation: means the process of determining whether a product or service is adequate to perform its intended function satisfactorily.

Verification: means the process of determining whether the quality or performance of a product or service is as stated, as intended or as required.

5.2 Abbreviations

AMAD	:	Activity Median Aerodynamic Diameter
CGS	:	Council for Geoscience
DAFF	:	Department of Agriculture, Forestry and Fisheries
DEA	:	Department of Environmental Affairs
DMR	:	Department of Mineral Resources
DWA	:	Department of Water Affairs
FEP	:	Features, Events and Processes
IAEA	:	International Atomic Energy Agency
ICRP	:	International Commission on Radiation Protection
LLD	:	Lower lever of detection
NEMA	:	National Environmental Management Amendment Act, Act No. 62 of 2008
NORM	:	Naturally Occurring Radioactive Material
NNR	:	National Nuclear Regulator
NNRA	:	National Nuclear Regulator Act, Act 47 of 1999
SSRP	:	Regulations in terms of section 36, read with section 47 of the National Nuclear Regulator act, 1999 (Act No. 47 of 1999), on Safety Standards and Regulatory Practices

6 ASSESSMENT METHODOLGY

6.1 Overview

Members of the public can be exposed to radiation via external or internal pathways associated with radioactive releases from authorized actions involving NORM.

These external and internal sources of radiation exposure in NORM activities include the following:

- Direct exposure from a point or volume source of ionizing radiation;
- External exposure from a plume of radionuclides in the atmosphere (cloud shine) or in water (water immersion source);
- Contact exposure from radionuclides on the skin;
- Radio nuclides deposited on the soil (ground shine) or sediment or building surface or vegetation;
- Radionuclides inhaled from the atmosphere;
- Radionuclides in the soil and water ingested through foodstuffs and drinking water;
- Inhalation of short-lived daughters of radon (also thoron for thorium ores)emanated from various sources; and
- Inhalation and ingestion of radionuclides re-suspended from soil and sediment.

The safety assessment process as depicted in Figure 1 is a generic guideline of how the systematic process should unfold to demonstrate safety of the public around NORM facilities and consists of the following elements:

- Site Description - A description of where the facility or plant is located;
- Process Description - A detailed description of all activities and processes at the facility or plant, which could result in public exposure;
- Sampling and analysis – A process through which the isotopic composition and the nuclide specific activity concentration of the radioactive nuclides in the source material on-site is determined.
- Quantify nuclides on-site - A detailed description of all the radionuclides present, their quantities, chemical and physical form, decay constants, dose conversion factors, absorption classes, and any other relevant information to the safety assessment;
- Source term quantification – The quantification, through calculation or modelling, of radioactive nuclides that can be released and dispersed into the environment to contribute to the public dose.
- Exposure Pathways - Identification of all intake and radiation exposure pathways relevant to the safety assessment;
- Critical Group Identification -Identification of all members of the public receiving the highest radiation doses, their habitat, agricultural and social activities that could impact on radiation doses through a source-pathway-receptor analysis and exposure scenario development;
- Assessment Criteria -The dose criteria to members of the public, contained in the legislative and regulatory framework (or criteria for radon concentrations), that should not be exceeded as a result of activities and operations at facilities;
- Public Dose Assessment – A complete dose assessment which should take into account all the exposure pathways and scenarios which requires some form of modelling based on conservative or reasonable assumptions. Results should be validated and uncertainties quantified;
    - Screening Dose Assessment -An initial safety assessment using most likely exposure scenarios and conservative input data. When the results of the screening safety assessment shows that dose to the public (and radon concentrations) are very low compared to assessment criteria, it may not be necessary to use site specific data.
    - Site Specific Dose Assessment -When results of a screening safety assessment exceed specific assessment criteria, then more realistic data and scenarios should be used; (See more details in section 6.7 and 6.8)
        - Sampling - When a site specific safety assessment is required, more detailed information should be provided on the nuclide compositions and specific operational activities;
        - Analysis - Samples should be analysed at accredited laboratories, and results should be included in the public dose assessment;
    - Interpretation of results - The results from the modelling and public safety assessment should be quantified and expressed in radiation dose values and compared with the regulatory criteria. This process should indicate whether any further dose reduction interventions should be considered to comply with the assessment criteria;
- Public Safety Assessment report - The assumptions, data, models and calculation results, validations, uncertainties and conclusions should be included in a safety assessment report and submitted to the NNR.

- NNR review - the evaluation of the public safety assessment against regulatory criteria could result in a reassessment of assumptions and parameters, including data from sampling and analysis programmes, before acceptance or approval of the submission.

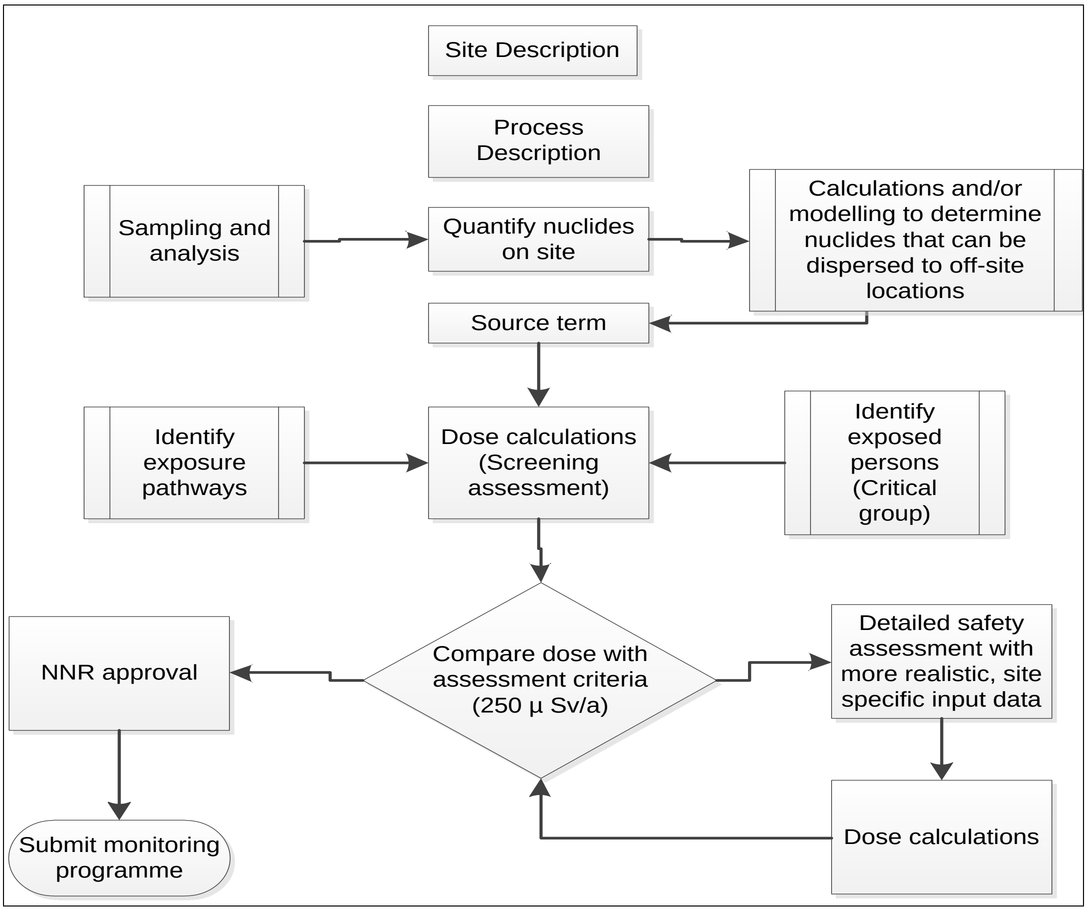

Figure 1: Public Safety Assessment Process

6.2 Site Description and Characterization

The site description and characterization should provide an overview of all significant sources, possible contaminant migration, dispersion and public exposure pathways. This information will aid in the planning of the assessment, the choice of suitable models and the implementation of a monitoring programme. The following information should be provided for the public safety assessment process:

- General climate description including seasonal variations;
- Geological and hydrological factors as well as topography;
- Biota;
- Historical information on radionuclide contamination levels in the environment e.g. past water surveys, sedimentation surveys activity concentration in soil and foodstuffs, etc. This could also be obtained from a baseline survey to determine the

background conditions against which measurements during the operational phase can be evaluated;

- Radionuclide data from exploration sampling (e.g. ppm U and Th of ore body)
- Input from operational experience and site inspections;
- Experiences from other sites locally and internationally;
- Information from Governmental and other Institutions, such as Department of Water Affairs (DWA), Council for Geoscience (CGS), Department of Agriculture Forestry and Fisheries (DAFF), etc, including studies on site water balance and sampling programmes of non-radioactive materials;
- Studies identifying known points of chemical pollution e.g. identification of groundwater plumes and sampling points;
- Identification of water uses and users e.g. municipalities, gardening, irrigation, farmers, use of mine water for drinking purposes, use of mine water for on-site irrigation, export to other users;
- Information on agricultural use of land, soil types, agricultural activities and information such as what type and quantity of food is produced, where the food is being distributed for consumption, etc.;
- Information on the type of settlements, such as informal settlements, housing types, etc.;
- Demography including information on the population such as ages, gender, eating habits, sources of food, etc.

6.3 Process Description

The process description should be provided in the public safety assessment to describe the activities and operations at a specific facility that could pose a radiation dose to the public via the relevant pathways. The process description should therefore contain information on all the facilities and the equipment on-site, as well as applications involving NORM. Experiences from other similar facilities, locally and internationally may also be usefully applied and extrapolated, especially for prospective assessments.

6.4 Source Term

6.4.1 Source term characterization

The location and nature of existing radioactive contamination and the levels of radionuclide concentrations present in the environment should be provided in the safety assessment in the form of or as part of a baseline report. The radioactive nuclides that are associated with the activities of the action with a potential to be released off-site to the environment, including both presently prevailing releases, and future predicted releases, should be determined.

The mode of release, chemical and physical characteristics, as well as the quantities of the radionuclides released, should be determined with the objective of computing the highest annual average dose to the critical group or groups during the operation of the facility or subsequent to closure thereof. Separate source terms should be developed for the airborne and aquatic pathways.

With regard to the development of source terms the following should be described:

a. Airborne pathways:

- Source terms of nuclides in gaseous and particulate releases via various actions (e.g. wind erosion, earth works, material handling, vehicle entrainment, stack releases) including possible upgrading of the nuclide concentrations in fine particles likely to become airborne;
- Physical and chemical properties of substances released;
- Elevation;
- Area and location of release;
- Release velocity;
- Mass flow rate Buoyancy (temperature) when applicable;
- Particle size distribution and activity (AMAD);
- Meteorology and climatology associated with releases;
- Dispersion of release, deposition and re-suspension at impact location.

b. Aquatic pathways:

- Source term of nuclides released and their radiological, physical, and chemical properties;
- Releases into surface water bodies;
- Releases into groundwater i.e. leaching and seepage;
- Migration of surface and groundwater off the site towards impact location as well as retardation and soil retention of nuclides;
- Extraction via wells or bore-holes;
- Chemical and physical characteristics impacting on radionuclide transport processes;
- Water body dynamics.

6.4.2 Progeny and Build up in the environment

Radioactive decay should be taken into account in the safety assessment, to account for the impact of the relevant progeny on the radiation doses.

Buildup of radionuclides in the environment due to sedimentation which could be a major contributing factor to radiation doses due to the long lived nature of radioactive nuclides released from NORM related activities should also be included in the safety assessment.

6.4.3 Exposure Pathways

Radiation exposures of the public from NORM activities may arise from the product(s) of a process, from the atmospheric or liquid discharges, from the re-use of by-product material(s) or from the disposal of solid waste(s). The most important routes of radiation exposure of the public are usually external gamma radiation, inhalation and ingestion. Relevant exposure pathways to be taken into account in NORM activities are the following:

- External exposure to gamma radiation;
- Internal exposure through dust inhalation;
- Internal exposure through ingestion;
- Skin contamination (from material deposited directly on the skin)

Figure 2 illustrates all the pathways by which an individual may be exposed and should be considered for dose calculations.

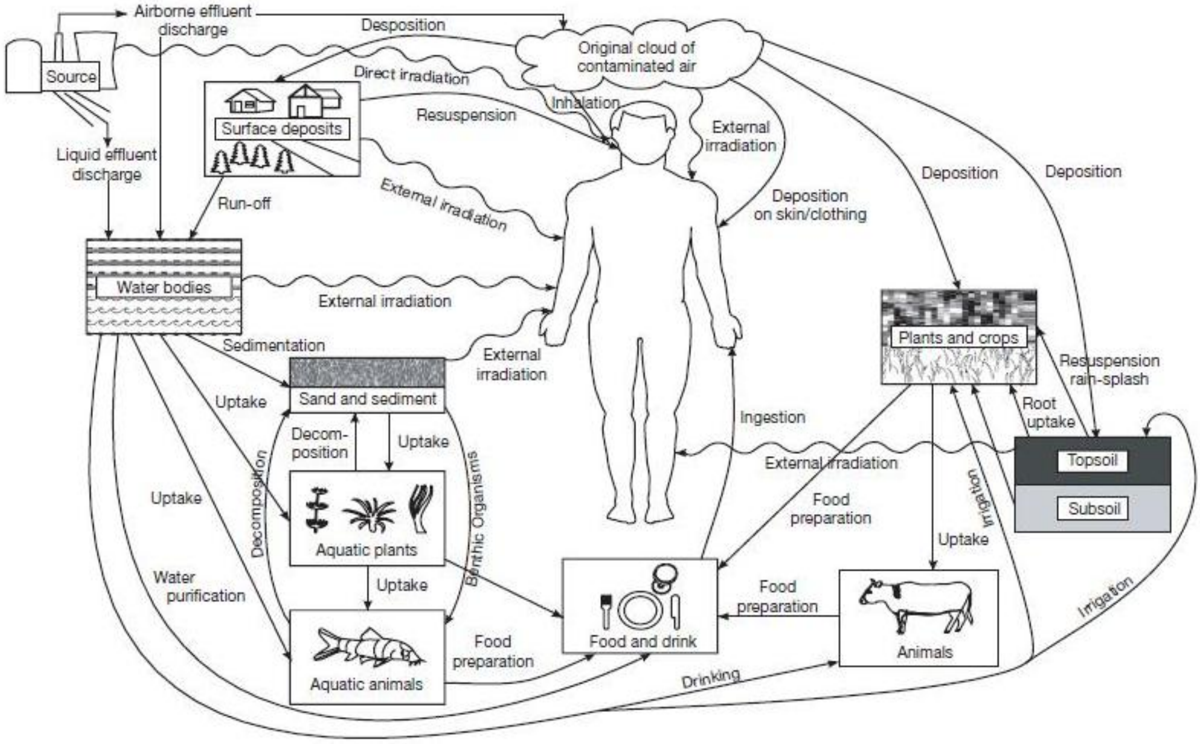

Figure 2: Exposure pathways for members of the public.

Factors which may be relevant to the transport of nuclides in the environment, should be addressed in the screening dose assessment, and if necessary, further considered in the model development. These should include the following items which are referred to as Features, Events and Processes (FEPs):

a. Natural features, events and processes including temporal variation, influencing the following radionuclide transport processes:
   - Dust emission through wind erosion
   - Radon exhalation
   - Atmospheric dispersion, deposition and re-suspension;
   - Soil erosion and sedimentation through water run-off
   - Surface water (rivers, lakes, wetlands) migration and sedimentation;
   - Groundwater migration and retardation;
   - Water transport through porous media;
   - Nuclide transfer to soil and food chain

b. Human activities which may impact on radiation safety:
   - Chemical changes by human action;
   - Chemical pollution;
   - Water Dam building;
   - Land reclamation;
   - Ploughing;
   - Recycling of solid materials;
   - Fertilization;
   - Agricultural activities;
   - Building of roads and buildings with contaminated material

c. Radionuclide transport mediated by human action:
   - Water extraction;

- Irrigation;
- Water recharge;
- Solid material handling and transport;
- Earth works;
- Feeding and watering of animals;

d. Events/processes related to human exposure through:
   External exposure:
   - Immersion in airborne plume;
   - Immersion in water;
   - Contaminated ground;
   - Contaminated shoreline and sediments

   Internal exposure:
   - Inhalation of radioactive gases and particulates;
   - Ingestion of terrestrial and aquatic foods and liquids

These FEPs are often used in the compilation of an interaction matrix.

6.5 Critical Group

The critical group is a group of members of the public which is reasonably homogeneous with respect to its exposure for a given radiation source and given exposure pathway and is typical of individuals receiving the highest effective dose or equivalent dose (as applicable) by the given exposure pathway from the given source. Therefore, in order to determine the dose to the public, the critical group should be defined and information such as radiation sources, the exposure pathways and the habitat of the individuals in the area around the facility should be provided.

6.5.1 Land Use

Land use data should be assessed to determine which activities could contribute to radiation dose and to determine the extent of the respective contributions. The following information should typically be included in the safety assessment:

- land devoted to agricultural uses, its extent, the crops and their yields;
- land devoted to dairy farming, its extent and yields;
- land devoted to industrial, institutional and recreational purposes, its extent and the characteristics of its use;
- bodies of water used for commercial, individual and recreational fishing, including details of the aquatic species fished, their abundance and yield;
- bodies of water used for commercial purposes, including navigation; community water supply, irrigation, and recreational purposes such as bathing and sailing;
- land and bodies of water supporting wildlife and livestock;
- direct and indirect pathways for potential radioactive contamination of the food-chain;
- products imported to or exported from the region which may form part of the food-chain;
- free foods such as mushrooms, berries and seaweed.

6.5.2 Habitation Study

A habitation study should be performed to provide data on the habits of the critical group in order to calculate a representative dose due to exposure to radionuclides while in the area of concern. The following type of data should be provided in the safety assessment:

- Quantities of foodstuffs, cultivated in the area, consumed;
- Quantities of livestock or produce from livestock, raised in the area, and consumed;
- Quantities of fish consumed from water bodies in the area of concern;
- Quantities of water, from a contaminated source, consumed;
- Time spent in the area of concern (indoors and outdoors) and time spent elsewhere; and
- Time spent in recreational activities, such as a dam or golf course, or whatever is situated in the area of concern.

6.5.3 Age Groups

Consumption rates and habitats for different age groups to be used in calculations of radiation doses should be included in the safety assessment (See Appendix 3).

6.6 Assessment Criteria

6.6.1 Screening Dose Criteria

For members of the public, the dose constraint applicable to the average member of the critical group within the exposed population is 250 µSv per annum specific to the authorised action unless otherwise agreed by the Regulator on a case-by-case basis, taking into account the dose limit of 1 mSv to exposure of members of the public from all sources. (This value excludes natural background) Table 1 provides the dose criteria for members of the public and the associated actions to be considered by applicants and holders of authorisations in the public safety assessment process.

Table 1: Public safety assessment dose criteria

Screening	Screening Result (µSv per annum)	Screening Action	Assessment Outcome
Assumed, conservative input data, sampling and analysis data (optional where applicable)	< 10	No further dose assessment required	Limited release monitoring, environmental monitoring and QA programme
	10 - 100	No further dose assessment required	Appropriate release monitoring, environmental monitoring and QA programme
	100 - 250	No further dose assessment required	Detailed release monitoring, environmental monitoring and QA programme
	> 250	Further assessment required using site specific data, detailed models and data	Plant modification, engineering back fitting and repeat assessment.

6.6.2 Screening Dose Assessment Criteria

When a graded approach for the safety assessment is used and an initial screening assessment is performed with generic data and conservative models, and the dose criterion value of 250 µSv per annum to the critical group is not exceeded, no further safety assessment would be required.

If the result of the safety assessment reveals a dose between 10 and 100 µSv per annum to the critical group an appropriate release, environmental monitoring and QA programme are required. If the result of the safety assessment reveals a dose between 100 and 250 µSv per annum to the critical group, detailed release monitoring, environmental monitoring and QA programmes are required.

6.6.3 Site Specific Assessment

If the dose criterion of 250 µSv per annum to the critical group is exceeded more detailed and realistic site input values maybe used to improve the reality of the assessment and reduce conservatism.

If the result of the safety assessment reveals a dose >250 µSv per annum to the critical group and the assessment was done with realistic habitat, consumption and release data, changes to plant systems and parameters will be required which would lead to a reduction in the amount of activity released to the environment. Build-up in the environment must be taken into account in the safety assessment as well as in the verification programme.

A detailed safety analysis may be performed from the onset, however, conducting an initial screening assessment and the results thereof should provide useful information on the amount of effort required.

6.7 Sampling

Monitoring programmes should be conducted with the following objectives:

- To characterize the source term by sampling and analysis of releases and environmental media,
- To provide input for validation of transport models,
- To identify unexpected environmental contamination, transfer routes and pathways.

Depending on the results obtained and the requirements of the transport models used, the monitoring programmes should be amended from time to time.
The following principles are applicable to Environmental Monitoring Programmes (See also Appendix 2):

- The programme should be comprehensive, representative and relevant to the facility or area monitored;
- Samples should be representative, adequately reflecting temporal and spatial variations in the medium sampled;
- Sampling of releases should be performed at intervals short enough to cover all phases of facility operations; for example a change in operating conditions may require a change in the sampling programme. In the case of environmental sampling, seasonal variations should be taken into account;

- The programme should be based on analysis of important pathways for the anticipated types and quantities of radionuclides released. The choice of sampling locations should be dictated by the objectives of the monitoring programme. Since the relevant radionuclides are also present naturally, control locations should also be sampled;
- The programme should consider the possibility of build-up of long-lived radionuclides in the environment;
- Monitoring programmes should be subjected to a periodic review (every 5 years) to ensure that it remains relevant for the purpose and to ensure that there are no discharge and environmental transfer routes, exposure pathways and changes in meteorological conditions that are overlooked;
- A back ground or reference site should be required when historical practices have been performed in the area that may have contributed to the increase in radionuclides in the environment;
- The quality of the sampling programme should be assured.

6.8 Sample Analysis

The analytical method that is capable of performing the measurement at the required sensitivity (usually background level) and accuracy should be acceptable to the NNR. In order to determine the acceptability of a method, scientific validation of the methodology should be provided to the NNR. This should entail the submission of sufficient information for the NNR to be able to make an informed decision on the acceptability of the method used (see Appendix 2).

In general, the main radionuclides to be analyzed for can be categorized as follows:

- Long lived alpha emitters: ^{238}U, ^{234}U, ^{230}Th, ^{226}Ra, ^{210}Po; ^{232}Th, ^{228}Th, ^{224}Ra;
- Beta emitters: ^{210}Pb, ^{228}Ra;
- ^{222}Rn and ^{220}Rn (and their progeny).

The specific radionuclides to be included in the analysis programme or modeling assessment will vary according to site specific factors (e.g. the uranium and thorium contents of the ores, process materials and wastes) and the specific exposure pathway under examination (gaseous, particulate, liquid, and nuclides contained in sedimentation). The exclusion of radionuclides from analysis programmes and modeling assessments must therefore be indicated and justified.

6.8.1 Screening Sample Analysis

A screening analysis should be applied at the initial phase of sampling and where activity concentrations are expected to be low. The results of such analysis should be conservative. For general screening of the total radioactivity it should be adequate to perform gross alpha–beta counting, applying suitable corrections for self-absorption. This method should be used for determining the total activities of the alpha emitting and beta emitting radionuclides, from which the ratio of the two can be obtained. This technique by using the alpha/beta ratio can provide clues as to the radionuclide composition, which may be useful in deciding upon subsequent analytical steps. If the total activity concentration is awarded to the most restrictive radionuclide in terms of dose contribution and the results of the safety assessment, expressed in dose, fall within the range of acceptability then no further analysis should be necessary. (Nuclide specific reference levels are the nuclide concentrations which will cause a chosen reference dose via all pathways. These can be derived from the reference dose. When the single, most restrictive nuclide is used, the activity limit will be obtained from the reference level divided by the dose conversion factor. Where more than one nuclide is used, the relative activity limit for each nuclide in the mixture must be determined from the reference dose. The sum of the dose from all nuclides in the mixture may not exceed the reference dose value.) Counting times should be selected to obtain the required lower limit of detection (LLD) for the materials concerned (i.e. about 10% of the applicable activity concentration level). Background and baseline data should be excluded as appropriate.

6.8.2 Nuclide Specific Sample Analysis

Where the total activity concentration is more than the activity concentration criterion for individual radionuclides, then further analysis should be conducted. Specific analysis techniques in Appendix 2 should then be applied.

6.9 Dose Assessment Process

6.9.1 Scenario Development

From the information above, real and/or hypothetical exposure scenarios should be developed defining the exposure conditions for members the critical group or groups as related to the various sources and pathways in terms of the models, parameters and dose coefficients to be used in the dose calculations discussed below.

6.9.2 Dose Calculations

The IAEA has defined models, parameters and dose coefficients which are appropriate for the calculation of age specific doses to the critical group of the public arising from intakes of radionuclides.

When assessing the resulting doses to a defined critical group arising from the internal and external exposure to radionuclides in the environment, the following factors should be considered where appropriate in the assessment:

- The age composition of the critical group and age related metabolic parameters e.g. breathing rates;
- Particle size and activity distribution i.e. AMAD;
- Radionuclide intakes and radionuclide specific dose coefficients;
- Gut uptake factors and lung clearance class (defined by radionuclide chemistry);
- Individual habits affecting exposure e.g. sleeping, activity periods spent indoors and outdoors;
- Culturally appropriate dietary and age specific food and water consumption rates;
- Gamma shielding factors

6.9.3 Input Parameters

For the development of the dose assessment model an interaction matrix which consists of a table indicating all possible elements and parameters in the assessment and interactions between them should be provided. It should commence with the source of radionuclides, runs through all possible dispersion pathways and ends at a final point of deposition, where the activity concentration at that point is converted into radiation dose to man. The use of such a table should facilitate the development of an audit trail of all decisions regarding the screening assessment, the subsequent detailed site specific assessment, and an iterative process towards the final results and conclusions (See Appendix 4).

At any stage in its development, the interaction matrix should be used to set up a quantitative model for the assessment. The various pathways should then be analyzed using computer models, hand calculations or direct measurements as appropriate. The use of conservative parameters and models should be used for the initial phases of the assessment. Depending on the assessment results obtained, progressive refinement, including uncertainty analysis as described in the section below, should be necessary to achieve the necessary confidence levels.

6.9.3.1 Atmospheric Emissions and Dispersion Modelling

Atmospheric discharges should include both gaseous and particulate releases from volume, area and point sources which may be chronic long term releases (e.g. slimes dams) or acute short term releases (e.g. roaster discharges).Atmospheric emissions should be calculated or determined for various natural or human activities causing such emissions (e.g. wind erosion, earth works, material handling and vehicle entrainment). Radon exhalation rates should also be calculated or determined for sources containing enhanced levels of Ra-226. Thoron exhalation rates may only be required if the material has high thorium and hence Ra-224 contents like monazite. The following types of sources should be addressed using different models or modelling options to calculate emissions due to natural and human processes:

Point sources including:

- Upcast ventilation shafts;
- Metallurgical processes e.g. stack releases, roaster discharges.

Volume and area sources including:

- Slimes dams;
- Pyrite and Calcine dumps;
- Open pit operations;
- Waste rock dumps;
- Ore stockpiles;
- Contaminated sites, rehabilitation and demolition activities;
- Dry evaporation dams.

Concentrations of atmospheric releases decrease with distance from the source due to their movement downwind, advection and dilution and dispersion. Information to predict radionuclide concentrations at the location of the critical group should be used in calculations such as:

- Source type;
- Radionuclide characteristics;
- Site topography;
- Site climate and wind patterns;
- Distance of critical group receptor from point of source.

As part of the screening assessment, a straight line Gaussian plume model may be used provided the terrain is fairly flat. A rationale should be provided for modelling assumptions used with regard to:

- Atmospheric stability categories;
- Topographical effects;
- Deposition parameters

In the absence of wind rose data the conservative approach should be adopted whereby it may be assumed that the wind blows directly towards the critical group at all times under worst case dispersion conditions.

Due to the considerable heights of tailings dams and waste dumps these should be modelled as volume sources rather than area sources. Alternatively, a conservative approach of assuming that the total emission is from a point source at the shortest distance between the source edge and the receptor, could be used.

6.9.3.2 Ground Water Modelling

Within a site there may be areas where significant releases of radionuclides from surface sources into the underlying groundwater occur. Potential sources on sites include seepage and/or run off from waste rock, slimes dams, evaporation pans, recharging operations and from other materials stockpiles e.g. calcine, pyrite. Polluted groundwater plumes may spread off the site into surrounding aquifers used by the public.

Where such plumes have been identified, the rate of movement down-slope and extent of the plume should be quantified as this may indicate aquifers potentially contaminated by radionuclides.

Potential release points of contaminated surface water to groundwater should be identified for each site and then quantitatively assessed through a combination of modelling and monitoring at available bore-holes and surface seepage points e.g. at the bottom of tailings dams or springs.

Where pollution plumes are identified, the primary purpose of modelling should be to predict rates of migration and interactions with potential critical groups in the long term. Groundwater pollution plumes should beidentified e.g. through sampling of available on and off site bore-holes and potential user groups should be identified by census.

6.9.3.3 Surface Water Modelling

The radionuclide source terms for modelling should be defined by an initial water sampling programme at critical points within the water balance based on a mixture of grab and composite samples. The radionuclide concentrations obtained should be entered directly into the transport model.

In the screening assessment it should be conservatively assumed that the nuclide concentrations in surface water at the first point of public access equals the concentration at the point of release except if justification for a less conservative approach can be provided.

6.9.3.4 Re-suspension of suspended radionuclides.

The activity concentration of re-suspended radionuclides should be included in dose calculations as the concentration of suspended and deposited radionuclides in sediments and on soil may become re-suspended when being disturbed which in turn may cause higher doses to members of the public.

6.9.3.5 Generic values

In the absence of site specific human consumption rates and habitation data, a list of generic or default values that should be used in dose calculations is provided in Appendix 3.

6.9.3.6 Transfer factors

In assessing the safety from releases of radionuclides into the environment, mathematical models are used in which the pathways of radionuclides from the release point to humans are quantitatively described by transfers between "environmental compartments" (e.g. from soil to pasture to cattle to humans). The radionuclide transfer between these compartments is usually described by transfer parameters.

In simple models these transfer parameters represent the ratio of concentrations of a radionuclide in two compartments under equilibrium conditions (referred to as the Concentration Factor Method). In more complex dynamic models an attempt is made to represent the time dependent movement of radionuclides between the various environmental compartments i.e. the model is a conceptual approximation of the kinetics of the real system.

Simple equilibrium models have been well described and documented and default values are available for many of the transfer parameters [38]. The Concentration Factor Method is adequate for many situations involving chronic releases of long lived radionuclides where equilibrium can be assumed in view of the timescales involved. Although it is usually sufficient in screening assessments to consider average conditions over prolonged periods, the combined effects of transient high release rates and unfavourable environmental situations involving substantial variations in release rates should be considered.

In contrast the parameters used in dynamic models (referred to as Systems Analysis method) tend to be model and site specific and their values depend upon the assumptions used in establishing the model.Two types of transfer parameters should be used in models:

- Individual parameters: These describe the transfer from one discrete environmental compartment to another e.g. from cattle feed or pasture to cattle.
- Aggregated parameters: These describe transfer via a complete chain of parameters e.g. the aggregated transfer parameter relating to radionuclide activity deposited on the soil surface to the concentration in the meat of grazing animals. This approach applies particularly to herds of cattle which do not receive additional feed or water from outside the area. In natural ecosystems this is an advantage as neither the individual transfer parameters to the various parts of the animal diet nor the animal diets themselves are well known.

The default transfer factors acceptable to the NNR that should be used in public safety assessments are listed in Appendix 3), except if other parameters can be justified.

6.9.3.7 Dose Coefficients

Dose coefficients from the latest version of the International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources should be used [39].

6.9.3.8 Time scales and Seasonal Variations [82]

The safety assessment should ensure equitable protection of both current and future generations and this will involve balancing greater certainty for shorter time periods with increasing uncertainty over longer time periods. The timescale of interest for an assessment is a function of the nature of the operational plant/facility/system and the external influences on it, and the longevity of the radionuclides involved. Therefore the timescales of an assessment should be justified on a case-by-case basis

In view of the fact that many of the processes involved in the migration of radioactive material through the environment (e.g. sedimentation in rivers, uptake into the food chain) are transient processes, the peak or plateau values should be determined in the safety assessment. In this regard the assessment process should determine the highest annual dose to the critical group or groups during the operation of the facility and should adequately account for the influence of seasonal factors. Post closure safety assessments should be performed separately and therefore does not form part of this guidance document (RG-002).

In addition to seasonal factors, consideration should also be given to abnormal weather conditions such as infrequent heavy rainfall and floods. A separate assessment should be prepared to assess the dose to the public under these conditions. Both assessed dose and frequency should be considered in the framework of a dose assessment.

6.9.4 Manual Methods

Where dose calculations are performed manually, a spread sheet is a handy tool to prevent duplication and it expedites the rate at which calculations are performed. The mathematical formulations used in the spread sheets should be presented in the safety assessment reports. The spread sheets should be systematically developed while the lay-out should also be described in the safety report as to supplement its review. Results should be captured in tables and included in safety assessment reports.

6.9.5 Codes and Software

There are various codes commercially available in the market. When codes are used, their validation and verification by the user is required and subsequent verification and acceptance by the NNR of the specific code is required in accordance with NNR requirements in [69].

6.9.5.1 Selection

The end product of dispersion modelling is an activity concentration, which should undergo further transportation according to the specific point of deposition, through ingestion, inhalation or external exposure. Codes should be selected on the basis of the required application and on grounds of the detail required for the safety assessment.

6.9.5.2 Validation and Verification

In terms of quality assurance on software and constituent models, the following should be addressed [69]:

Where the results of a code application are used to demonstrate compliance with the regulatory limits, the code should be bench-marked against actual measurements sufficiently representative of the situations for which the code is to be applied. This should demonstrate that the code is conservative for the particular application, or result in uncertainties which can be used in the overall analysis.

For a screening assessment, it should be sufficient to provide a rationale for the use of a particular code, for a given application, by referring to published information or expert opinion instead of code benchmarking. The justification should provide sufficient evidence to the effect that the uncertainties in the code do not result in underestimation of the dose to the critical group.

6.9.5.3 Quality Assurance

The NNR requirements [61] should be applied to the public safety assessment process. The applicant or holder of an authorisation should identify and document the processes needed for the quality management programme with regards to Radiation Protection and determine the sequence and interaction of these processes, ensure the availability of resources and information necessary to support the operation and monitoring of these processes, monitor, measure and analyse these processes, and implement actions necessary to achieve planned results and continual improvement.

The public safety assessment should cover elements such as control of documents; control of records; managements responsibilities; radiation protection function; design and development; control of monitoring and measuring devices; measurement, analysis and improvement; internal audits; continual improvements; corrective actions; and preventative actions.

6.9.6 Sensitivity Analysis

Sensitivity analysis (SA) is the study of how a specific input parameter would affect the output of a model (numerical or otherwise), e.g. variations in the wind speed in an air dispersion model. The extent to which sensitivity analyses are applied will depend on the amount of conservatism applied in each safety assessment and has to be justified on a case-by-case basis.

A sensitivity analysis should be provided in the safety assessment process which includes:

- Supporting the decision making or the development of recommendations for decision makers (e.g. testing the robustness of a result);
- Enhancing communication from modellers to decision makers (e.g. by making recommendations more credible, understandable, compelling or persuasive);
- Increasing the understanding or quantification of the system (e.g. understanding relationships between input and output variables); and
- Modeling of development (e.g. searching for errors in the model).

6.9.7 Uncertainty Analysis

Uncertainty in the assessment methodology arises from possible departures of the real situation from the assumptions outlined in the assessment context. Although analytical methods are widely used, rigorous testing to quantify uncertainty under all potential conditions of model application should be provided. The extent to which uncertainty analyses are applied will depend on the amount of conservatism applied in each safety assessment and has to be justified on a case-by-case basis.

The calculation method should present a detailed derivation of the uncertainty bounds to be associated with important results. The modeling should provide a realistic calculation of any particular phenomenon to a degree of accuracy compatible with the current state of knowledge of that phenomenon. The neglect or simplification of any phenomenon should not be treated by including a deliberate pessimism or bias, but should form part of an assessment of the overall modelling uncertainty.

In arriving at the overall calculational uncertainty all sources of uncertainty including scaling uncertainties and uncertainties associated with initial and boundary conditions should be taken into account. The methodology used to combine the various sources of calculation uncertainty should be described and justified. Judgments concerning dominant phenomena and key models should be clearly stated and justified. For each parameter, which is judged to be of particular significance to the derivation of the overall uncertainty, justification should be provided for the assumed uncertainty distribution of that parameter.

6.9.8 Interpretation of results

A step-wise iterative procedure should be used to assess critical group doses and should focus on those aspects of the assessment that could give the highest doses. The initial assessment should be performed with conservative data. The assessment result should be benchmarked against the predetermined dose criterion. If the dose criterion is not exceeded, the level of detail in the assessment is acceptable. When the dose criterion is exceeded, a more detailed assessment should be conducted, using more realistic data. An iterative process should be repeated until the most realistic data and site specific data is used. If these results still exceed reference levels, physical actions should be implemented to reduce the source term and limit exposure scenarios.

7 SUBMISSIONS TO NNR

In making submissions of safety assessments to the NNR, the structure used in the Table of Contents of this guide (RG-002) should be followed as far as possible.

APPENDIX 1: CRITICAL GROUP CONCEPT

The critical group should be representative of those individuals in the population expected to receive the highest levels of dose from a particular source or group of sources. The group should be small enough to be relatively homogenous with respect to those factors (e.g. age, diet and behaviour) that affect the doses received. It is also necessary to choose the time when these doses are at a maximum value. The weighted mean individual dose in the critical group is then assessed against the relevant dose limit.

In most cases the critical group will be a group of individuals who live locally and are located close to the emission source. This population will include people who because of their habits and activities will receive doses substantially greater than those of other exposed groups in the surrounding population. Because of the innate variability within an apparently homogenous group some members of the critical group will therefore receive doses somewhat higher than the mean dose for the group.

The maximum size of a critical group normally ranges up to no more than a few tens of individuals. In extreme cases it may be convenient to define it in terms of a single hypothetical individual.

The total dose to a particular critical group may arise from a number of sources on a single site or from multiple sites and therefore a critical group defined on the basis of radiation exposure from one radionuclide and one environmental pathway may be exposed via other pathways and other nuclides. Account must be taken of exposure from all pathways and radionuclides that contribute to the total dose of the group.

Identification of the individuals that are considered as the critical group for a particular radionuclide and exposure pathway may present some practical difficulties. Specific guidance on using statistical methods to identify the critical group from an exposed population is available [75].

In order that the identified critical group may be reasonably homogenous with respect to dose, the factors which affect the doses must be identified e.g. location, physical and metabolic characteristics, age distribution, dietary habits, consumption patterns, types of dwellings, occupancy factors and other habits. For example, a range of dietary habits (e.g. food consumption rate corresponding to a ratio of not more than three between the maximum observed and the mean characterizing the critical group is considered sufficient to satisfy the homogeneity requirement.

The nature of the critical group is liable to change with time owing to variations in the use of the environments to which releases are made and in the location and habits of potentially exposed populations. It is desirable to make allowances at the outset for these variations when defining the critical group e.g. by using conservative parameters acting to maximise assumptions.

It is important to keep critical groups under review and to amend assessments in the light of any changes.

The extent of the safety assessment may be expanded as required to include radiation dose impact of a wider range of affected and/or potentially affected parties.

APPENDIX 2: SAMPLING AND ANALYSIS

Sampling must be performed according to procedures acceptable to the NNR and should include and address the information and aspects below [6], [7], [8], [9], [10].

A2.1 Sampling of Particulate Emissions

All release of radionuclides to the environment should be controlled at the source of origin. Therefore the initial sampling programme, prior to authorisation, should be focused on verifying the prior (prospective) calculations of the source term. The sampling must be comprehensive enough to accurately quantify all possibly present radionuclides. It should be followed, after obtaining the NNR authorisation, by a monitoring programme based upon long term integrated measurements that adequately account for operational and seasonal variations. A combination of modelling and measurement should also be used.

A2.2 Sampling of Liquid Discharges

Sampling programmes are required:

- Initially to characterize the level of radionuclide contamination in liquid source terms on and around the site (determining background or baseline).
- For the verification of assumptions made in the prospective safety assessment on the quantity of specific radionuclides released. (A safety assessment cannot be based on assumptions only. Verification of assumptions by sampling and analysis is required, unless assumptions can be proven to be very conservative).
- For longer term monitoring of releases, surface and groundwater, therefore demonstration of compliance with condition of authorisation. The initial sampling programme (baseline sampling programme) would follow prior (prospective) calculations and would then require identifying radionuclide contamination in:
    - Liquid source terms on the site.
    - Planned and (potential) unplanned releases off the site.
    - Seepage and recharge from surface sources to groundwater.
    - Surface waters (e.g. rivers and lakes) and groundwater (pollution plumes) on and around the site.
    - Mine waters used for irrigation, for drinking water and export to other users (farmers and municipalities); groundwater used for domestic purposes, irrigation and animal watering.
    - Dewatering operations.
- Initially, prior to operation, potential emissions will be calculated. However, as soon as operational data becomes available, the calculations must be verified and validated.

In the long term, sampling programmes should address seasonal and other variations and future impacts e.g. potential impacts of groundwater plumes.

The initial sampling programme should be based upon site characteristics, local topography, geohydrological factors and the identification of known water users.

The subtraction of "background activity" from a water sample is not generally appropriate. In those cases where there are inputs from other sources e.g. when comparing surface water or groundwater quality from points upstream and downstream of the site, subtraction should be appropriate to determine the net contamination and dose attributed to a specific site release. Groundwater sampling programmes should include some control locations at a higher point on the water gradient away from identified seepage points.

Water sampling programmes should involve grab samples taken weekly, monthly or quarterly. This approach may be appropriate where contamination levels are well characterized and relatively constant. Composite sampling should be considered as this provides better long term average values.

The initial sampling programme (or comprehensive baseline) in the pre-authorization phase to characterize the site and environs should be comprehensive. As the site characterization proceeds, the sampling frequency and the number of sampling points should usually decrease. The time over which this occurs would usually be site specific and may range from as short as six months for stable situations to several years with more complex assessments. The site characterization programme should form the basis for the monitoring programme implemented in the operational phase.

A2.3 Sampling of sediments

Prior to authorization, all downstream spots where sedimentation may occur should be identified and sampled to quantify the background activity concentration of radionuclides present in the medium, thus forming a reference baseline before operation commences. These spots should include dams, riverbeds, etc. Deposited radionuclides will contribute to dose when re-suspended through processes such as irrigation or being churned up by physical movement, etc. Therefore sampling should include surface depositions as well as a selection of samples at depth.

Initially alpha-beta analysis should suffice as a scan. In situ gamma spectrometry measurements may also be useful as a scan on dry sediments. Where significant activity is measured, detailed analysis should be required. This activity concentration should be used as a baseline or background value, when the dose to the critical group is calculated. All exposure pathways should be considered. The accumulation of nuclides from all future releases into the environment, after the action has been authorized by the NNR, should not lead to an increase in annual dose to the critical group that exceeds the dose constraint applicable to that site. The safety assessment and the definition of the critical group should be periodically revisited to ensure that initial assumption with regards to land use and inhabitant consumption rates have not changed. Therefore control at source is of utmost importance.

A2.4 Statistics

A representative sample of the area and of the media should be provided. Seasonal variations should be considered in terms of the area. In order to determine media representatively the number of samples should give a good reflection of the activity concentration spread in that media. If for example soil samples are to be taken on a 100 m^2 piece of land, the results should be sufficient to project a realistic estimate of spread of nuclides on that area. The results should also identify hot spots where activity concentrations are higher than the average, because those areas could lead to higher dose and should be considered in the dose assessment.

A2.5 Analysis

The analytical method that is capable of performing the measurement at the required sensitivity (usually background level) and accuracy should be acceptable to the NNR. In order to determine the acceptability of a method, scientific validation of the methodology should be provided to the NNR. This should entail the submission of sufficient information for the NNR to be able to make an informed decision on the acceptability of the method used.

A2.6 Gross Alpha and Nuclide Specific Analysis

The main radionuclides of interest should be defined and the required measurement sensitivity when appropriate analytical protocols are considered. The techniques employed for a particular sample, should be chosen judiciously. For general screening of the total radioactivity it should be adequate to perform gross alpha–beta counting, applying suitable corrections for self-absorption. Counting times should be selected to obtain the required lower level of detection (LLD) for the materials concerned (i.e. about 10% of the applicable activity concentration level).

A2.7 Analytical Methods

For analysis of the individual radionuclides of interest, the following analytical techniques should be applied:

<u>X ray fluorescence (XRF) spectrometry [33]:</u>

The XRF method is widely used to measure the elemental composition of materials and is well suited to the rapid determination of uranium and thorium. There are two types of spectrometer, both of which can be used for this application:

(i) Wavelength dispersive spectrometers, in which photons are separated by diffraction on an analyzing crystal before being detected.
(ii) Energy dispersive spectrometers, in which the detector allows the determination of the energy of the photon when it is detected. These spectrometers are smaller and cheaper than wavelength dispersive spectrometers and the measurement is faster, but the resolution and detection limit are not as good.

<u>Instrumental neutron activation analysis (INAA) [33]:</u>

INAA, a technique involving the irradiation of the sample material with neutrons in a nuclear reactor, is a highly sensitive analytical technique for performing both qualitative and quantitative analyses of major, minor and trace elements in bulk samples. It is well suited to the determination of uranium and thorium.

<u>Inductively coupled plasma atomic emission spectroscopy (ICP-AES)[33]:</u>

ICP-AES is used for the chemical analysis of aqueous solutions of rocks and other materials and is suitable for the determination of a wide range of major elements and a limited number of trace elements. Sample preparation involves the digestion of the powdered material with 40 vol. % hydrofluoric acid mixed with either per-chloric or nitric acid. Some minerals such as chromite, zircon, rutile and tourmaline will not completely dissolve using this digestion procedure. For samples containing substantial amounts of these minerals, XRF analysis is probably more appropriate.

Inductively coupled plasma mass spectroscopy (ICP-MS) [33]:

ICP-MS is used to determine trace elements in aqueous solutions. The technique is well suited to determination of uranium and thorium. The sample preparation procedure is the same as that for ICP-AES.

High energy gamma spectrometry (high purity germanium crystal (HPGe)) [33]:

This technique provides a quantification of the important radionuclide ^{226}Ra, along with ^{228}Ra and ^{228}Th. The method can also be used to quantify the ^{238}U concentration, but with a higher LLD.

Low energy gamma spectrometry (HPGe) [33]:

This technique entails a relatively short counting time of 4 hours and gives a quantification of ^{238}U and ^{210}Pb (as well as ^{235}U). It is also possible for the technique to provide a determination of ^{226}Ra (as well as radionuclides of lesser interest: ^{227}Ac, ^{231}Pa and ^{230}Th), but with a higher LLD.

Sample digestion and alpha spectrometry [33]:

This technique is suitable for quantifying the ^{210}Po concentration. It involves a relatively long counting time.

The application of the above mentioned techniques is summarized in the table below. The minimum sample size needed is in each case about 10 grams. The following conversions from parts per million to Becquerel (Bq) per gram are required:

1 ppm uranium = 0.012348 Bq ^{238}U per gram of material;
1 ppm thorium = 0.004057 Bq ^{232}Th per gram of material.

For material associated with most industrial processes, it is adequate to have a basic analytical infrastructure consisting of XRF in combination with a background shielded, thin window HPGe gamma spectrometry system. Only in those processes where ^{210}Po is of concern will radiochemical techniques in combination with alpha spectrometry be required. Although ^{40}K is unlikely to be of concern its activity concentration can be determined at no additional cost, especially if both XRF and gamma spectrometry are used for radionuclide analysis. This may be useful when ^{40}K is present in significant concentrations, since it can be used to deduce information on other radionuclides and to improve the quality assurance of the measurements.

TABLE A2.1: ANALYTICAL TECHNIQUES FOR DETERMINING RADIONUCLIDE ACTIVITY CONCENTRATIONS [33]

Radionuclide	Suitable technique	Comment
^{238}U, ^{232}Th (and 40K)	XRF, INAA, ICP-AES, ICP-MS	Sensitivity of 1 ppm uranium or thorium achievable with any of these techniques (equivalent to about 0.01 Bq/g ^{238}U and 0.004 Bq/g ^{232}Th)
^{226}Ra, ^{228}Ra, ^{228}Th(and ^{40}K)	High energy gamma spectrometry	The presence of uranium may interfere with the direct determination of ^{226}Ra For indirect determination of ^{226}Ra, gas-tight sealing for 3 weeks is needed to ensure equilibrium with progeny (^{214}Pb, ^{214}Bi) LLD of 0.1 Bq/g requires equipment that is well shielded from background radiation High sensitivity (>25%) and high resolution HPGe detectors required Counting times of a few hours per sample are adequate High density materials (>2.5 g/cm3) may need self absorption corrections
^{210}Pb	Low energy gamma spectrometry	Self-absorption corrections required LLD of 0.1 Bq/g requires equipment that is well shielded from background radiation Counting times of a few hours per sample are adequate
^{210}Po	Sample digestion plus alpha spectrometry	Microwave acid digestion required Validated radiochemical separation techniques required Counting times of a few hours per sample are adequate to achieve an LLD of 0.1 Bq/g

A2.8 Measurement of ^{222}Rn [22], [74]

Many techniques are available for measuring radon, thoron and their progeny. Although radon progeny are responsible for most of the radiation exposure of the respiratory tract, the parent radon governs the airborne concentrations of the progeny.

In active techniques (i.e. those that require power for operation), such as those based on the use of well-established and robust ZnS (Ag) Lucas scintillation cells, a sample of air is drawn into the cell. Scintillations caused by alpha radiation inside the cell are counted. Flow-through versions of these cells can be connected to appropriate counting and recording devices to create a continuous monitor. Continuous monitors are useful when it is necessary to monitor the time dependence of concentrations of radon or radon progeny.

Radon progeny can be measured by analyzing the airborne radioactive material collected on a filter or with continuous decay product monitors. For rapid surveys, canisters containing activated charcoal can be exposed to air for a few days. These devices collect, in a reproducible manner, a fraction of the radon that enters the canister. The amount of radioactive material collected in the activated charcoal is evaluated by gamma spectroscopy or by liquid scintillation counting. This evaluation is normally done in a central laboratory.

Sensitive ‘electret’ ion chamber (EIC) devices can also be used for short term measurements. These are small ion chambers in which the collecting voltage is supplied by an electret (electrically charged insulator). The electrical charge of the electret decreases as ions created by radiation are collected. The charge difference in the electret before and after radon exposure is related to the product of average radon concentration and exposure time by a calibration factor. A correction term for ambient gamma radiation is necessary. For this purpose a second electret measuring only the gamma background is often used. The response of electrets can be affected in conditions of high humidity. Because of temporal variations in radon concentrations it is good practice for measurements of indoor radon or its progeny to be averaged over as long a period as practicable.

The alpha track detector is the most widely used type of radon detector for long term measurements. It consists of a small plastic container inside which is mounted a small piece of solid state nuclear track detector (SSNTD) material. The SSNTD material behaves as an alpha particle detector. The most commonly used SSNTD materials in passive radon detectors are plastics known as CR-39 and LR-115, and polycarbonate. The opening to the detection volume within the plastic container may be fitted with a filter to prevent the entry of radon progeny and to retard the entry of thoron. In some widely used radon detectors of this type the container has a very narrow entrance slit that acts as a diffusion barrier, thus obviating the need for a filter. A fraction of the alpha particles from radon and its short lived progeny decaying within the sensitive volume of the device strike the SSNTD material and produce submicroscopic damage tracks. After the exposure period the devices are returned to a laboratory where the SSNTD material is etched either chemically or electrochemically in a strong caustic solution. The etching process transforms the submicroscopic damage tracks into tracks that are readily visible under optical magnification. The number of tracks can be counted either visually or with an automated device. The number of tracks is related to the product of average radon concentration and exposure time by a calibration factor which must be determined empirically.

Where thoron also is to be measured, special detectors, using SSNTD material within two interconnected detecting volumes, have been designed to measure both radon and thoron levels.

TABLE A2.2: OPERATIONAL CHARACTERISTICS OF SOME COMMON MEASUREMENT PROCEDURES FOR RADON GAS AND POTENTIAL ALPHA ENERGY CONCENTRATION (PAEC) OF RADON PROGENY IN AIR

Substance measured	**Duration**	**Common example of method**	**Typical delay after sampling**	**Measurement**
Rn gas	Long	SSNTDs	Laboratory analysis necessary	-
		EICs	1 h to establish constant diffusion conditions	5 min with special voltmeter
	Long or short	Lucas –cell flow through	2,5 hours to allow equilibration of radon progeny	At necessary intervals in alpha counter
		Diffusion cell	2,5 hours to establish constant diffusion conditions	60 minutes in alpha counter
	Short	Lucas cell	2,5 hours to allow equilibration of radon progeny	60 minutes in alpha counter
		Charcoal canister	Laboratory analysis required	
		Atmos 12 DPX	1 hour to allow progeny ratios to stabilize	At necessary intervals
		Alpha guard PQ 2000	1 hour to allow progeny ratios to stabilize	At necessary intervals
		Two filter method	A few minutes to place the filter in the counter	60 minutes in alpha counter
PAEC	Long or short	CAE and ALGADE dosimeter	Laboratory analysis required	
		Thomson and Nielson radon WL meter	1 hour to allow for progeny ratios to stabilize	60 minutes in alpha counter
	Short	GAMP	A few minutes to place filter in counter	5 - 6 minutes in alpha counter

A2.9 Consideration of background

It is important to characterize a site with respect to the natural background radioactive nature. The samples taken should therefore represent the concentrations of radionuclides in nature before human intervention. A site in the area should therefore be chosen and justified to bear samples of representative nature. The activity concentration in these areas should be subtracted from values obtained at the site to be characterized. Background values should be used as reference values for restoration, remediation and removal from regulatory control.

APPENDIX 3: DEFAULT VALUES FOR USE IN SCREENING ASSESSMENTS

Site specific values should be justified and used after acceptance by the NNR. Published values for radionuclide specific transfer parameters in the literature for a specific pathway may vary widely due to the wide variations encountered in natural ecosystems and organisms. Numerous parameter values are often incorporated into data files attached to mathematical models; these values may vary widely from model to model resulting in a wide range of predicted dose values for a specific pathway when using different models. Conservative default values are defined for screening assessments so as to produce a low probability of the relevant dose limit being exceeded when the calculated dose is less than one order of magnitude lower than the dose limit. This expectation is dependent upon the source terms being well defined or conservatively estimated and that all major exposure pathways are included in the model.

In order to ensure that predicted values are consistent and comparable default parameter values have been defined by the NNR and should specifically be used for screening assessments. This includes default values for transfer factors, consumption rates, dose coefficients, shielding factors, occupancy times etc.

A3.1 Units

The units in the sections below should be applied to parameters used in the public dose calculations.

A3.2 AMAD

In dose calculations to members of the public, particulate sizes of 1µm should be used.[49]

A3.3 External and Age Specific Internal Dose Coefficients

The dose coefficients from [47], [48], [49], and [79] for different age groups should be used. The most conservative values should be used for specific nuclides or the use of other values should be justified (e.g. fast dissolution rate values).

TABLE A3.1: EXTERNAL DOSE COEFFICIENTS [49]

Nuclide	Water Immersion dose coefficients (Sv/Bq s m^{-3})	Air Submersion dose coefficients (Sv/Bq s m^{-3})	Ground Surface dose coefficients (Sv/Bq s m^{-2})	Dose Coefficients for Exposure to Soil Contaminated to a Depth of 15 cm (Sv/Bq s m^{-3})	Dose Coefficients for Exposure to Soil Contaminated to an Infinite Depth (Sv/Bq s m^{-3})
Tl-208	1.77E-13	3.84E-16	1.69E-13	9.68E-17	1.23E-16
Pb-210	1.31E-19	5.64E-17	2.13E-18	1.31E-20	1.31E-20
Pb-211	5.41E-18	2.49E-15	5.08E-17	1.46E-18	1.64E-18
Pb-212	1.52E-17	6.87E-15	1.43E-16	3.62E-18	3.77E-18
Pb-214	2.59E-17	1.18E-14	2.44E-16	6.70E-18	7.18E-18
Bi-210	6.33E-20	3.29E-17	1.05E-18	1.86E-20	1.93E-20
Bi-212	2.00E-17	9.24E-15	1.79E-16	5.36E-18	6.27E-18
Bi-214	1.66E-16	7.65E-14	1.41E-15	4.36E-17	5.25E-17
Po-210	9.03E-22	4.16E-19	8.29E-21	2.45E-22	2.80E-22
Po-214	8.85E-21	4.08E-18	8.13E-20	2.40E-21	2.75E-21
Po-218	9.71E-22	4.48E-19	8.88E-21	2.63E-22	3.02E-22
At-218	2.75E-19	1.19E-16	4.18E-18	3.13E-20	3.13E-20
Rn-222	4.16E-20	1.91E-17	3.95E-19	1.14E-20	1.26E-20
Ra-223	1.35E-17	6.09E-15	1.28E-16	3.10E-18	3.23E-18
Ra-224	1.03E-18	4.71E-16	9.57E-18	2.62E-19	2.74E-19
Ra-226	6.59E-19	3.15E-16	6.44E-18	1.65E-19	1.70E-19
Ac-227	1.30E-20	5.82E-18	1.57E-19	2.62E-21	2.65E-21
Ac-228	1.04E-16	4.78E-14	9.28E-16	2.76E-17	3.20E-17
Th-227	1.07E-17	4.88E-15	1.04E-16	2.65E-18	2.79E-18

Nuclide	Water Immersion dose coefficients (Sv/Bq s m^{-3})	Air Submersion dose coefficients (Sv/Bq s m^{-3})	Ground Surface dose coefficients (Sv/Bq s m^{-2})	Dose Coefficients for Exposure to Soil Contaminated to a Depth of 15 cm (Sv/Bq s m^{-3})	Dose Coefficients for Exposure to Soil Contaminated to an Infinite Depth (Sv/Bq s m^{-3})
Th-228	2.05E-19	9.20E-17	2.35E-18	4.17E-20	4.25E-20
Th-230	3.94E-20	1.74E-17	7.50E-19	6.39E-21	6.47E-21
Th-231	1.18E-18	5.22E-16	1.85E-17	1.94E-19	1.95E-19
Th-232	1.99E-20	8.72E-18	5.51E-19	2.78E-21	2.79E-21
Th-234	7.64E-19	3.38E-16	8.32E-18	1.29E-19	1.29E-19
Pa-234	2.03E-16	9.34E-14	1.84E-15	5.38E-17	6.18E-17
Pa-234m	1.52E-18	7.19E-16	1.53E-17	4.20E-19	4.20E-19
U-234	1.75E-20	7.63E-18	7.48E-19	2.14E-21	2.15E-21
U-235	1.59E-17	7.20E-15	1.48E-16	3.75E-18	3.86E-18
U-238	7.95E-21	3.41E-18	5.51E-19	5.52E-22	5.52E-22

TABLE A3.2: INHALATION DOSE COEFFICIENTS [39, 49]

Nuclide	Half Life	Type	AMAD	f1	Newborn	f2	1 year old	5 year old	10 year old	15 year old	Adult
Pb-210	22.3y	F	1	0.600	4.70E-06	0.200	2.90E-06	1.50E-06	1.40E-06	1.30E-06	9.00E-07
Pb-210	22.3y	M	1	0.200	5.00E-06	0.100	3.70E-06	2.20E-06	1.50E-06	1.30E-06	1.10E-06
Pb-210	22.3y	S	1	0.020	1.80E-05	0.010	1.80E-05	1.10E-05	7.20E-06	5.90E-06	5.60E-06
Pb-211	0.601h	F	1	0.600	2.50E-08	0.200	1.70E-08	8.70E-09	6.10E-09	4.60E-09	3.90E-09
Pb-211	0.601h	M	1	0.200	6.20E-08	0.100	4.50E-08	2.50E-08	1.90E-08	1.40E-08	1.10E-08
Pb-211	0.601h	S	1	0.020	6.60E-08	0.010	4.80E-08	2.70E-08	2.00E-08	1.50E-08	1.20E-08
Pb-212	10.6h	F	1	0.600	1.90E-07	0.200	1.20E-07	5.40E-08	3.50E-08	2.00E-08	1.80E-08
Pb-212	10.6h	M	1	0.200	6.20E-07	0.100	4.60E-07	3.00E-07	2.20E-07	2.20E-07	1.70E-07
Pb-212	10.6h	S	1	0.020	6.70E-07	0.010	5.00E-07	3.30E-07	2.50E-07	2.40E-07	1.90E-07
Pb-214	26.8m	F	1	0.600	2.20E-08	0.200	1.50E-08	6.90E-09	4.80E-09	3.30E-09	2.80E-09
Pb-214	26.8m	M	1	0.200	6.40E-08	0.100	4.60E-08	2.60E-08	1.90E-08	1.40E-08	1.40E-08
Pb-214	26.8m	S	1	0.020	6.90E-08	0.010	5.00E-08	2.80E-08	2.10E-08	1.50E-08	1.50E-08
Bi-210	5.012d	F	1	0.010	1.10E-08	0.050	6.90E-09	3.20E-09	2.10E-09	1.30E-09	1.10E-09
Bi-210	5.012d	M	1	0.010	3.90E-07	0.050	3.00E-07	1.90E-07	1.30E-07	1.10E-07	9.30E-08
Bi-212	1.01h	F	1	0.100	6.50E-08	0.050	4.50E-08	2.10E-08	1.50E-08	1.00E-08	9.10E+09
Bi-212	1.01h	M	1	0.100	1.60E-07	0.050	1.10E-07	6.00E-08	4.40E-08	3.80E-08	3.10E-08
Bi-214	19.9m	F	1	0.010	5.00E-08	0.050	3.50E-08	1.60E-08	1.10E-08	8.20E-09	7.10E-09
Bi-214	19.9m	M	1	0.010	8.70E-08	0.050	6.10E-08	3.10E-08	2.20E-08	1.70E-08	1.40E-08
Po-210	138.38d	F	1	0.200	7.40E-06	0.100	4.80E-06	2.20E-06	1.30E-06	7.70E-07	6.10E-07
Po-210	138.38d	M	1	0.200	1.50E-05	0.100	1.10E-05	6.70E-06	4.60E-06	4.00E-06	3.30E-06
Po-210	138.38d	S	1	0.020	1.80E-05	0.010	1.40E-05	8.60E-06	5.90E-06	5.10E-06	4.30E-06
Ra-223	11.4d	F	1	0.600	3.00E-06	0.200	1.00E-06	4.90E-07	4.00E-07	3.30E-07	1.20E-07
Ra-223	11.4d	M	1	0.200	2.80E-05	0.100	2.10E-05	1.30E-05	9.90E-06	9.40E-06	7.40E-06
Ra-223	11.4d	S	1	0.020	3.20E-05	0.010	2.40E-05	1.50E-05	1.10E-05	1.10E-05	8.70E-06

Nuclide	Half Life	Type	AMAD	f1	Newborn	f2	1 year old	5 year old	10 year old	15 year old	Adult
Ra-224	3.66d	F	1	0.600	1.50E-06	0.200	6.00E-07	2.90E-07	2.20E-07	1.70E-07	7.50E-08
Ra-224	3.66d	M	1	0.200	1.10E-05	0.100	8.20E-06	5.30E-06	3.90E-06	3.70E-06	3.00E-06
Ra-224	3.66d	S	1	0.020	1.20E-05	0.010	9.20E-06	5.90E-06	4.40E-06	4.20E-06	3.40E-06
Ra-226	1600y	F	1	0.600	2.60E-06	0.200	9.40E-07	5.50E-07	7.20E-07	1.30E-06	3.60E-07
Ra-226	1600y	M	1	0.200	1.50E-05	0.100	1.10E-05	7.00E-06	4.90E-06	4.50E-06	3.50E-06
Ra-226	1600y	S	1	0.020	3.40E-05	0.010	2.90E-05	1.90E-05	1.20E-05	1.00E-05	9.50E-06
Ra-228	5.75y	F	1	0.600	1.70E-05	0.200	5.70E-06	3.10E-06	3.60E-06	4.60E-06	9.00E-07
Ra-228	5.75y	M	1	0.200	1.50E-05	0.100	1.00E-05	6.30E-06	4.60E-06	4.40E-06	2.60E+06
Ra-228	5.75y	S	1	0.020	4.90E-05	0.010	4.80E-05	3.20E+05	2.00E-05	1.60E-05	1.60E-05
Ac-227	2.8y	F	1	0.005	1.70E-03	0.0005	1.60E-03	1.00E-03	7.20E-04	5.60E-04	5.50E-04
Ac-227	2.8y	M	1	0.005	5.70E-04	0.0005	5.50E-04	3.90E-04	2.60E-04	2.30E-04	2.20E-04
Ac-227	2.8y	S	1	0.005	2.20E-04	0.0005	2.00E-04	1.30E-04	8.70E-05	7.60E-05	7.20E-05
Ac-228	6.13h	F	1	0.005	1.80E-07	0.0005	1.60E-07	9.70E-08	5.70E-08	2.90E-08	2.50E-08
Ac-228	6.13h	M	1	0.005	8.40E-08	0.0005	7.30E-08	4.70E-08	2.90E-08	2.00E-08	1.70E-08
Ac-228	6.13h	S	1	0.005	6.40E-08	0.0005	5.30E-08	3.30E-08	2.20E-08	1.90E-08	1.60E-08
Th-227	18.7d	F	1	0.005	8.40E-06	0.0005	5.20E-06	2.60E-06	1.60E-06	1.00E-06	6.70E+07
Th-227	18.7d	M	1	0.005	3.20E-05	0.0005	2.50E-05	1.60E-05	1.10E-05	1.10E-05	8.50E-06
Th-227	18.7d	S	1	0.005	3.90E-05	0.0005	3.00E-05	1.90E-05	1.40E-05	1.30E-05	1.00E-05
Th-228	1.91y	F	1	0.005	1.80E-04	0.0005	1.50E-04	8.30E-05	5.20E-05	3.60E-05	2.90E-05
Th-228	1.91y	M	1	0.005	1.30E-04	0.0005	1.10E-04	6.80E-05	4.60E+05	3.90E-05	3.20E-05
Th-228	1.91y	S	1	0.005	1.60E-04	0.0005	1.30E-04	8.20E-05	5.50E-05	4.70E-05	4.00E-05
Th-230	7.7E+04y	F	1	0.005	2.10E-04	0.0005	2.00E-04	1.40E-04	1.10E-04	9.90E-05	1.00E-04
Th-230	7.7E+04y	M	1	0.005	7.70E-05	0.0005	7.40E-05	5.50E-05	4.30E-05	4.20E-05	4.30E-05
Th-230	7.7E+04y	S	1	0.005	4.00E-05	0.0005	3.50E-05	2.40E-05	1.60E-05	1.50E-05	1.40E-05
Th-231	1.06d	F	1	0.005	1.10E-09	0.0005	7.20E-10	2.60E-10	1.60E-10	9.10E-11	7.80E-11
Th-231	1.06d	M	1	0.005	2.20E-09	0.0005	1.60E-09	8.00E-10	4.80E-10	3.80E-10	3.10E-10

Nuclide	Half Life	Type	AMAD	f1	Newborn	f2	1 year old	5 year old	10 year old	15 year old	Adult
Th-231	1.06d	S	1	0.005	2.40E-09	0.0005	1.70E-09	7.60E-10	5.20E-10	4.10E-10	3.30E-10
Th-232	1.4E+10y	F	1	0.005	2.30E-04	0.0005	2.20E-04	1.60E-04	1.30E-04	1.20E-04	1.10E-04
Th-232	1.4E+10y	M	1	0.005	8.30E-05	0.0005	8.10E+05	6.30E-05	5.00E-05	4.70E-05	4.50E-05
Th-232	1.4E+10y	S	1	0.005	5.40E-05	0.0005	5.00E-05	3.70E-05	2.60E-05	2.50E-05	2.50E-05
Th-234	24.10d	F	1	0.005	4.00E-08	0.0005	2.50E-08	1.10E-08	6.10E-09	3.50E-09	2.50E-09
Th-234	24.10d	M	1	0.005	3.90E-08	0.0005	2.90E-08	1.50E-08	1.00E-08	7.90E-09	6.60E-09
Th-234	24.10d	S	1	0.005	4.10E-08	0.0005	3.10E-08	1.70E-08	1.10E-08	9.10E-09	7.70E-09
Pa-231	3.27E+04y	M	1	0.005	2.20E-04	0.0005	2.30E-04	1.90E-04	1.50E-04	1.50E-04	1.40E-04
Pa-231	3.27E+04y	S	1	0.005	7.40E-05	0.0005	6.90E-05	5.20E-05	3.90E-05	3.60E-05	3.40E-05
Pa-234	6.70h	M	1	0.005	2.80E-09	0.0005	2.00E-09	1.00E-09	6.80E-10	4.70E-10	3.80E-10
Pa-234	6.70h	S	1	0.005	2.90E-09	0.0005	2.10E-09	1.10E-09	7.10E-10	5.00E-10	4.00E-10
U-234	2.445E+5y	F	1	0.040	2.10E-06	0.020	1.40E-06	9.00E-07	8.00E-07	8.20E-07	5.60E-07
U-234	2.445E+5y	M	1	0.040	1.50E-05	0.020	1.10E-05	7.00E-06	4.80E-06	4.20E-06	3.50E-06
U-234	2.445E+5y	S	1	0.020	3.30E-05	0.002	2.90E-05	1.90E-05	1.20E-05	1.00E-05	9.40E-06
U-235	7.04e+08y	F	1	0.040	2.00E-06	0.020	1.30E-06	8.50E-07	7.50E-07	7.70E-07	5.20E-07
U-235	7.04e+08y	M	1	0.040	1.30E-05	0.020	1.00E-05	6.30E-06	4.30E-06	3.70E-06	3.10E-06
U-235	7.04e+08y	S	1	0.020	3.00E-05	0.002	2.60E-05	1.70E-05	1.10E-05	9.20E-06	8.50E-06
U-238	4.468E9y	F	1	0.040	1.90E-06	0.020	1.30E-06	8.20E-07	7.30E-07	7.40E-07	5.00E-07
U-238	4.468E9y	M	1	0.040	1.20E-05	0.020	9.40E-06	5.90E-06	4.00E-06	3.40E-06	2.90E-06
U-238	4.468E9y	S	1	0.020	2.90E-05	0.002	2.50E-05	1.60E-05	1.00E-05	8.70E-06	8.00E-06

f1 – fraction for newborn
f2 - fraction for all other age group
F – Fast absorption class
M – Medium absorption class
S – Slow absorption class

TABLE A3.3: INGESTION DOSE COEFFICIENTS [39] [49]

Nuclide	Half Life	f1	Newborn	f2	1 year old	5 year old	10 year old	15 year old	Adult
Pb-210	22.3y	0.600	8.40E-06	0.200	3.60E-06	2.20E-06	1.90E-06	1.90E-06	6.90E-07
Pb-211	0.601h	0.600	3.10E-09	0.200	1.40E-09	7.10E-10	4.10E-10	2.70E-10	1.80E-10
Pb-212	10.6h	0.600	1.50E-07	0.200	6.30E-08	3.30E-08	2.00E-08	1.30E-08	6.00E-09
Pb-214	26.8m	0.600	2.70E-09	0.200	1.00E-09	5.20E-10	3.10E-10	2.00E-10	1.40E-10
Bi-210	5.012d	0.100	1.50E-08	0.050	9.70E-09	4.80E-09	2.90E-09	1.60E-09	1.30E-09
Bi-212	1.01h	0.100	3.20E-09	0.050	1.80E-09	8.70E-10	5.00E-10	3.30E-10	2.60E-10
Bi-214	19.9m	0.100	1.40E-09	0.050	7.40E-10	3.60E-10	2.10E-10	1.40E-10	1.10E-10
Po-210	138.38d	1.000	2.60E-05	0.500	8.80E-06	4.40E-06	2.60E-06	1.60E-06	1.20E-06
Ra-223	11.4d	0.600	5.30E-06	0.200	1.10E-06	5.70E-07	4.50E-07	3.70E-07	1.00E-07
Ra-224	3.66d	0.600	2.70E-06	0.200	6.60E-07	3.50E-07	2.60E-07	2.00E-07	6.50E-08
Ra-226	1600y	0.600	4.70E-06	0.200	9.60E-07	6.20E-07	8.00E-07	1.50E-06	2.80E-07
Ra-228	5.75y	0.600	3.00E-05	0.200	5.70E-06	3.40E-06	3.90E-06	5.30E-06	6.90E-06
Ac-227	21.8y	0.005	3.30E-05	0.0005	3.10E-06	2.20E-06	1.50E-06	1.20E-06	1.10E-06
Ac-228	6.13h	0.005	7.40E-09	0.0005	2.80E-09	1.40E-09	8.70E-10	5.30E-10	4.30E-10
Th-227	18.7d	0.005	3.00E-07	0.0005	7.00E-08	3.60E-08	2.30E-08	1.50E-08	8.80E-09
Th-228	1.91y	0.005	3.70E-06	0.0005	3.70E-07	2.20E-07	1.50E-07	9.40E-08	7.20E-08
Th-230	7.7E4y	0.005	4.10E-06	0.0005	4.10E-07	3.10E-07	2.40E-07	2.20E-07	2.10E-07
Th-231	1.06d	0.005	3.90E-09	0.0005	2.50E-09	1.20E-09	7.40E-10	4.20E-10	3.40E-10
Th-232	1.4E+10y	0.005	4.60E-06	0.0005	4.50E-07	3.50E-07	2.90E-07	2.50E-07	2.30E-07
Th-234	24.10d	0.005	4.00E-08	0.0005	2.50E-08	1.30E-08	7.40E-09	4.20E-09	3.40E-09
Pa-231	3.27E+04y	0.005	1.30E-05	0.0005	1.30E-06	1.10E-06	9.20E-07	8.00E-07	7.10E-07
Pa-234	6.70h	0.005	5.00E-09	0.0005	3.20E-09	1.70E-09	1.00E-09	6.40E-10	5.10E-10
U-234	2.445E5y	0.040	3.70E-07	0.020	1.30E-07	8.80E-08	7.40E-08	7.40E-08	4.90E-08
U-235	7.04E+08y	0.040	3.50E-07	0.020	1.30E-07	8.50E-08	7.10E-08	7.00E-08	4.70E-08
U-238	4.468E9y	0.040	3.40E-07	0.020	1.20E-07	8.00E-08	6.80E-08	6.70E-08	4.50E-08

f1 - fraction for newborn, f2 - fraction for all other age groups, F – Fast absorption class, M – Medium absorption class, S – Slow absorption class

A3.4 Occupancy Factors [72] [80]

Default occupancy factors for screening assessments are provided below:

TABLE A3.4: DEFAULT OCCUPANCY FACTORS [72] [80]

Activity	Adults	15 year old	10 year old	5 year old	1year old	Newborn	Reference
Time spent Indoors	7050	7665	7568	7775	7914	8760	US EPA 600, 2011
Time spent outdoors	1710	1095	1192	985	846	0	US EPA 600, 2011
Total hours per year (24 x 365)	8760						
Soil and dust ingestion (General population) (mg/a)	7 300 mg/a	18 250 mg/a	36 500 mg/a	18 250 mg/a	10 800 mg/a	0 mg/a	US EPA 600, 2011
Inhalation rates	22.08 m^3/d	20.16 m^3/d	15.36 m^3/d	8.88 m^3/d	5.28 m^3/d		ICRP 101 Table A1
Working on contaminated sediments and land (e.g. irrigated land)	2000	0	0	0	0	0	Assumption
Playing on sand	0	410	410	365	110	0	US EPA 600, 2011
Playing on grass	365	460	445	480	320	0	US EPA 600, 2011
Playing in dirt	0	300	383	383	200	0	US EPA 600, 2011
Swimming	9	27.8	30.2	27.4	19.2	0	US EPA 600, 2011
Fishing (10% 0f outdoor time)	170	110	76	78	0	0	Assumption
Boating (10% of outdoor time)	170	110	76	78	0	0	Assumption

A3.5 Gamma Shielding Factors [72]

Arising from plumes or ground deposits
Brick houses: indoor dose rate taken as 60% of outdoor value
Other houses e.g. wood: indoor dose rate taken as 90% of outdoor value
(Typical shielding factors used in codes: Resrad – 0.7; DandD – 0.5512 [81])

A3.6 Radon Indoors at Home and Work [72]

Default values regarding Equilibrium Factors (F) and dose conversions from radon concentrations ($Bq.m^{-3}$) to effective dose in mSv per annum from [46] should be included in the safety assessment. Values were taken from ICRP 65, assuming 7000 hours per year indoors and 2000 hours per year at work and an equilibrium factor of 0.4

TABLE A3.5: RADON EQUILIBRIUM FACTORS [72]

Quantity	Unit	Value
Radon progeny conversion	($mJ.h.m^{-3}$) per WLM	3.54
Radon progeny/radon exposure conversions (equilibrium factor 0.4)	($mJ.h.m^{-3}$) per ($Bq.h.m^{-3}$) WLM per ($Bq.h.m^{-3}$)	2.22E-06 6.28E-07
Annual exposure to radon progeny per unit radon concentration		
At home	($mJ.h.m^{-3}$) per ($Bq.m^{-3}$)	1.56E-02
At work	($mJ.h.m^{-3}$) per ($Bq.m^{-3}$)	4.45E-03
At home	WLM per ($Bq.m^{-3}$)	4.40E-03
At work	WLM per ($Bq.m^{-3}$)	1.26E-03
Dose conversion convention, effective dose per unit exposure to radon progeny:		
At home	mSv ($mJ.h.m^{-3}$)	1.1
At work	mSv ($mJ.h.m^{-3}$)	1.4
Dose conversion convention, effective dose per unit exposure to radon progeny:		
At home	mSv per WLM	4
At work	mSv per WLM	5
Radon progeny/radon concentration conversion		
With equilibrium factor F=0.4	WL per ($Bq.m^{-3}$)	1.07E-04
In general	WL per ($Bq.m^{-3}$)	2.67E-4

A3.7 Radon Emanation [22]

The radon flux from an uncovered tailings pile is directly related to the radium activity, the emanation coefficient and the bulk density. The general radon flux rate, F_t , for tailings with thicknesses of less than 2 meters, can be calculated with the following equation:

$F_t = R.\rho.E.\ \overline{\lambda Dt}.\ \tanh\left(\ \overline{\lambda Dt}.x_t\right)$,
where F_t ($Bq.m^{-2}.s^{-1}$) is the total radon flux, R ($Bq.kg^{-1}$) is the radium concentration,
ρ ($kg.m^{-3}$) is the tailings density,

E (dimensionless) is the radon emanation coefficient,
λ (s^{-1}) is the radon decay constant, D ($m^2.s^{-1}$) is the diffusion coefficient,
and x (m) is the thickness of the tailings.

Where the tailings thickness is more than 2m for wet tailings and more than 4m for dry tailings, the equation is reduced to:

$F_t = R.\rho.E.\ \overline{\lambda D t}.$

The average emanation coefficients recommended by the USNRC is 0.25 to 0.35.
The diffusion coefficient used in Australia are D = 4.2E-06 for tailings thickness of more than 25 cm and D = 1E-05 $(1\text{-}m)^3$ + 4.2E-10 for tailing less than 25 cm thick.

A3.8 Default Annual Consumption Factors for Exposed Individuals in the Critical Group [78]

TABLE A3.6: DEFAULT ANNUAL CONSUMPTION FACTORS [78]

CATEGORY	Kg per year fresh weight				
	ADULTS	**15 year old**	**10 year old**	**5 year old**	**1 year old**
% of Adult	100	85	60	50	40
Water (L/a)	600	510	360	300	240
Soil (kg/a)	0.037	0.03145	0.0222	0.0185	0.0148
Fresh water Fish (kg/a)	25	21.25	15	12.5	10
Milk (L/a)	120	102	72	60	48
Beef (kg/a)	30	25.5	18	15	12
Mutton (kg/a)	25	21.25	15	12.5	10
Pork (kg/a)	20	17	12	10	8
Poultry (kg/a)	50	42.5	30	25	20
Eggs (kg/a)	15	12.75	9	7.5	6
Grain (kg/a)	250	212.5	150	125	100

- A average of consumption values was established from international literature which includes values obtained from South African national food balance sheets [78]

TABEL A3.7: AGE GROUP CONSUMPTION RATIOS [72]

Age group	% of adult consumption value
Adult	100
15	85
10	60
5	50
1	40

A3.9 Uptake of Radionuclides from Soil by Edible Portions of Vegetation [38]

The transfer factor, F_v, for the uptake of nuclides from soil to plant is defined as the ratio of the dry weight concentration in the plant to the dry weight concentration in the specified soil.

For fruit, however, $F_{v,}$ is the concentration ration of the wet weight concentration in the fruit to the dry weight concentration in the soil.

A3.10 Temperate Environments: Mean Radionuclide transfer to plants Fv [38]

TABLE A3.8: TEMPERATE ENVIRONMENTS: MEAN RADIONUCLIDE TRANSFER TO PLANTS (FV) [38]

Element	Plant group	Plant Compartment	Soil group	Mean value
Pb	Cereals	Grain	All	1.1E-2
		Stem and shoots	All	2.3E-2
	Maize	Grain	All	1.2E-3
		Stem and shoots	All	2.8E-3
	Leafy vegetables	Leaves	All	8.0E-2
			Sand	7.3E-2
			Loam	8.2E-1
			Clay	2.8E-2
	Non-leafy vegetables	Fruit, heads berries, buds	All	1.5E-2
		Stems and shoots	All	8.8E-3
	Leguminous vegetables	Seeds and pods	All	5.3E-3
			Sand	2.7E-3
			Loam	1.4E-3
			Clay	8.0E-4
		Stems and shoots	All	8.0E-4
	Root crops	Roots	All	1.5E-2
			Sand	6.4E-2
			Loam	2.3E-3
		Stems and shoots	All	6.3E-2
	Grasses	Stems and shoots	All	3.1E-1
	Pastures	Stems and shoots	All	9.2E-2
Po	Cereal	Grain	All	2.4E-4
	Maize	Grain	All	2.4E-4
	Leafy vegetables	Leaves	All	7.4E-3
	Non-leafy vegetables	Stems and shoots	All	1.9E-4
	Root crops	Roots	All	5.8E-3
		Stems and shoots	All	7.7E-2

Element	Plant group	Plant Compartment	Soil group	Mean value
Po	Pastures	Stems and shoots	All	1.2E-1
Pu	Cereals	Grain	All	9.5E-6
			Sand	3.3E-5
			Loam	4.9E-6
			Clay	7.4E-6
			Organic	5.4E-4
		Stems and roots	All	4.4E-5
	Maize	Grain	All	3.0E-6
		Stems and roots	All	5.2E-5
	Leafy vegetables	Leaves	All	8.3E-5
			Sand	1.1E-4
			Loam	2.8E-4
			Organic	2.7E-5
	Non-leafy vegetables	Fruit, heads, berries, buds	All	6.5E-5
	Roots and crops	Roots	All	3.9E-4
			Sand	5.5E-4
		Leaves	All	1.2E-3
	Grasses	Stems and shoots	All	1.6E-4
	Pastures	Stems and shoots	All	5.5E-4
Ra	Cereal	Grain	All	1.7E-2
			Loam	2.9E-2
			Clay	3.9E-2
		Stems and shoots	All	3.6E-2
			Loam	5.2E-2
	Maize	Grain	All	2.4E-3
			Loam	1.7E-3
			Clay	1.4E-3
		Stems and shoots	All	1.8E-2
	Leafy vegetables	Leaves	All	9.1E-2
			Loam	1.2E-1
			Clay	4.0E-2
			Organic	4.9E-2
	Non-leafy vegetables	Fruits, heads, berries, buds	All	1.7E-2
			Sand	2.2E-3
			Loam	4.8E-2
			Clay	2.2E-2
		Stems and shoots	All	6.1E-2
	Root crops	Roots	All	7.0E-2

Element	Plant group	Plant Compartment	Soil group	Mean value
Ra			Sand	4.8E-3
			Loam	9.1E-2
			Clay	3.9E-2
		Stems and shoots	All	7.1E-2
			Loam	1.5E-1
	Other	Sunflower	All	4.2E-1
		Tea leaves	All	3.3E-2
	Grasses	Stems and shoots	All	1.3E-1
			Sand	1.4E-1
			Loam	2.6E-1
			Clay	4.2E-2
	Pasture	Stems and shoots	All	7.1E-2
			Sand	8.0E-3
			Loam	8.8E-3
Th	Cereals	Grain	All	2.1E-3
			Sand	4.4E-3
			Loam	2.7E-3
			Clay	1.2E-3
		Stems and shoots	All	6.1E-3
			Sand	1.4E-2
			Loam	6.6E-3
			Clay	3.6E-3
			Organic	2.0E-3
	Maize	Grain	All	6.4E-5
			Loam	2.0E-4
			Clay	1.5E-5
		Stems and shoots	All	1.8E-3
	Leafy vegetables	Leaves	All	1.2E-3
			Loam	8.6E-4
			Clay	4.9E-4
	Non-leafy vegetables	Fruits, heads, berries, buds	All	7.8E-4
			Loam	2.0E-4
			Clay	1.5E-5
		Stems and shoots	All	2.2E-3
	Root crops	Roots	All	8.0E-4
			Loam	1.1E-3
			Clay	2.6E-4
		Stems and shoots	All	8.7E-3
	Grasses	Stems and	All	4.2E-2

		shoots		
Element	**Plant group**	**Plant Compartment**	**Soil group**	**Mean value**
Th	Pastures	Stems and shoots	All	9.9E-2
U	Cereals	Grain	All	6.2E-3
			Sand	8.9E-3
			Loam	7.7E-3
			Clay	3.8E-3
		Stems and shoots	All	2.7E-2
			Sand	3.4E-2
			Loam	5.4E-2
			Clay	1.0E-2
	Maize	Grain	All	1.5E-2
		Stems and shoots	All	7.8E-3
	Leafy vegetables	Leaves	All	2.0E-2
			Sand	1.7E-1
			Loam	4.3E-2
			Clay	3.6E-3
			Organic	1.8E-1
	Non-leafy vegetables	Fruits, heads, berries, buds	All	1.5E-2
			Sand	1.9E-2
			Loam	2.3E-2
			Clay	1.8E-2
		Stems and shoots	All	5.3E-2
	Root crops	Roots	All	8.4E-3
			Sand	7.8E-3
			Loam	2.5E-2
			Clay	6.8E-3
		Stems and shoots	All	2.8E-2
			Sand	2.5E-2
			Loam	5.0E-2
			Clay	1.1E-2
	Other	Sunflower (leaves)	All	7.1E-2
			Sand	4.1E-1
			Loam	7.1E-2
			Clay	2.7E-2
		Sunflower (grain)	All	1.5E-2
	Grasses	Stems and shoots	All	1.7E-2
			Sand	1.6E-2
			Loam	9.8E-3

Element	Plant group	Plant Compartment	Soil group	Mean value
U	Pastures	Stems and shoots	All	4.6E-2
			Sand	2.7E-3
			Loam	7.2E-2

A3.11 Transfer factors [38]

The transfer of radionuclides from animal feeds to milk is commonly described by using the transfer coefficient $\boldsymbol{F_m}$ defined as:

"the fraction of the animals total daily intake of a radionuclide that is transferred to each litre of milk per day". (assume16 kg of dry matter per day for lactating cows and 1.5 kg of dry matter per day for sheep and goats.) The values given above apply to cows. Tables also exist for goat and sheep milk in [38].

A3.12 Transfer Coefficients $\boldsymbol{F_f}$ for Animal Flesh Beef, Mutton, Goat, Pork, Poultry, Egg [38]

The transfer of radionuclides from animals feed (pasture, grass, forage) to edible animal products is commonly described by using the transfer coefficient $\boldsymbol{F_f}$ defined as:
"the fraction of the animals total daily intake of a radionuclide that is transferred to each kg of flesh at equilibrium or at time of slaughter".

The values below for beef meat may be applied to other types of edible meat where relevant.

TABLE A3.9: TRANSFER COEFFICIENTS F_f FOR ANIMAL FLESH [38]

Element	Transfer coeff. to beef (d/kg)	Transfer coeff. to milk (d/L)	Transfer coeff. to mutton (d/kg)	Transfer coeff. to poultry (d/kg)	Transfer coeff. to eggs (d/kg)
U	3.9E-04	1.8E-03	3.0E-02	7.5E-01	1.1E+00
Ra	1.7E-03	3.8E-04	5.0E-03	9.9E-04	2.0E-05
Pb	7.0E-04	1.9E-04	7.10E-03	2.0E-03	2.0E-03
Po	5.0E-03	2.1E-04	5.0E-03	2.4E+00	3.1E+00
Th	2.3E-04	5.0E-06	5.0E-03	4.0E-03	2.0E-03

A3.13 Animal Daily Food and Water Consumption Default Values [38], [72]

TABLE A 3.10: ANIMAL DAILY FOOD AND WATER CONSUMPTION DEFAULT VALUES [38], [72]

Animal	Water (L/d)	Dry Feed[a] (kg/d)	Soil ingestion (kg/d)
Milk or Beef Cow	75	16	1.25
Sheep, Goats, Pigs, Calves	15	1.5	0.8
Chickens	0.3	0.15	

[a] Feed, pasture, browse or forage

A3.14 Wet/dry mass ratio [38]

TABLE A3.11: WET/DRY MASS RATIO [38]

Substance	wet/dry ratio
Maize	0.85
Wheat	0.88
Oats	0.87
Barley	0.87
Sorghum	0.87
Grass	0.20
Pasture	0.20
Cauliflower	0.11
Cabbage	0.12
Lettuce	0.08
onion	0.11
Spinach	0.08
Celery	0.06
Tomato	0.06
Cucumber	0.06
Pumpkin	0.06
Beetroot	0.16
Carrot	0.14
Patato	0.21
Rasberry	0.16
Watermelon	0.07
Apple	15.6
Pear	16.8
Peach	10.9
Apricot	14.7
Orange	0.14
Grape	0.184

A3.15 K_d factors [38]

K_d is the ratio of the concentration of radionuclide sorbed on a specified solid phase to the radionuclide concentration in a specified liquid phase.

TABLE A3.12: K_D FACTORS [38]

K_d according to texture - organic matter criterion (L/kg)					
Element	**All soils**	**Mineral**	**Organic**	**Sand+ Loam**	**Clay**
U	2.00E+02	1.80E+02	1.20E+03		
Th	1.90E+03	2.60E+03	7.30E+02		
Ac	1.70E+03	1.20E+03	5.40E+03		
Bi	4.80E+02	3.50E+02	1.50E+03		
Pa	2.00E+03	1.40E+03	6.60E+03		
Pb	2.00E+03	2.20E+02	1.30E+04		
Po	2.10E+02	1.90E+02	6.60E+03		
Ra	2.50E+03		1.30E+03	1.90E+03	3.80E+04

A3.16 Default Concentration Factors for Freshwater Fish [38]

Under equilibrium conditions, the incorporation of radioactivity into fish can be expressed as the bioaccumulation factor B_p defined as:
"the ratio of the activity concentration in fish tissue to that in water which is expressed as $\mathrm{Bq.kg^{-1}}$.wet weight fish per $\mathrm{Bq.kg^{-1}}$ (or $\mathrm{L^{-1}}$) water (units of $\mathrm{L.kg^{-1}}$)."
The activity concentration in fish tissue refers to the edible portion (muscle) of the fish wet mass.
The values can be used to predict activity levels in edible fish tissue from activity levels in water [38].

A3.17 Summary of mean bioaccumulation factors B_p for freshwater fish tissue (L/kg fresh weight) [38]

TABLE A3.13: MEAN BIOACCUMULATION FACTORS (B_P)FOR FRESHWATER FISH TISSUE [38]

Element	Whole body	Muscle
U	2.4E+00	9.6E-01
Ra	2.1E+02	4.0E+00
Pb	3.7E+02	2.5E+01
Th	1.9E+02	6.0E+00

A3.18 Summary of mean sediment to biota concentration ratios for edible tissues of freshwater fish (Ratio of concentration of radionuclide in an organism on a fresh weight basis to the radionuclide concentration in the sediment) [38]

TABLE A3.14: MEAN SEDIMENT TO BIOTA CONCENTRATION RATIOS FOR EDIBLE TISSUES OF FRESHWATER FISH [38]

Element	Whole fish	Fish muscle	Fish liver
Pb	2.9E-01	1.1E-01	2.2E-03

A3.19 Resuspension Factor [38]

The characterization of resuspension is complicated. The extent of resuspension depends on the material, the surface type and time elapsed since deposition. However, the following generic values could be used [38]:

Rural conditions: $Ks(t) = 1.2E\text{-}6\ t^{-1}\ (m^{-1})$
Urban environments $Ks(t) = 10^{-}E(-0.01.t) + 10^{-9}\ (m^{-1})$
Arid and desert conditions $Ks(t) = 10^{-6}E(-0.15\ \bar{t}) + 10^{-9}\ (m^{-1})$
Where t refers to the time in days since deposition.

APPENDIX 4: INTERACTION MATRIX

The interaction matrix should be drawn up as follows:

- List all sources of radioactive material, as identified during the site characterization process.
- Identify the release and dispersion pathway. Apply the features, events and process list to determine the process that could lead to dispersion.
- Every dispersion process ends at a point of deposition.
- Repeatedly apply the FEP list at the point of deposition until there in no further dispersion possible.
- The activity concentrations at all dispersion points where human exposure from internal or external sources of radiation is possible (directly or indirectly) should be quantified and translated into dose to man from that source at that point. Otherwise an acceptable justification should be provided why a pathway or receptor is not considered (e.g. when similar previous assessments indicated that exposures are negligible).

The following example where the source is a tailings dam is simplified to illustrate the interaction matrix principles:

- The dispersion pathway could be atmospheric and aquatic, therefore both pathways should be further explored. For this illustration only the atmospheric pathway is considered.
- Radioactive nuclides are released through emission and dispersed by wind in the form of particulates.
- Particulates are deposited on soil, and on terrestrial plants.
- The soil and terrestrial plant dispersion pathways should be further evaluated.
- In the case of only soil being assessed, the exposure of the public is affected by spending time on the soil which should be quantified.
- Nuclides in the soil can be further dispersed by re-suspension, ploughing, irrigation, and run off. Each pathway should be considered.
- Ploughing would lead to subsurface activity concentrations of radioactive nuclides, which would be absorbed by the agricultural activities on that land, which could be cattle feed, or fresh produce. The specific pathway should be analysed.
- In the example, root vegetables are produced. The activity in the soil is transferred to the root vegetables, for which a transfer factor [38] should be used to quantify the extent of transfer.
- The activity concentration in the edible part of the root should then be quantified. The activity concentration in the root should be multiplied by the human consumption rate and a dose conversion factor, to determine the dose to man.
- All doses should be summed to determine the total dose to members of the public from a given source.

The safety assessment methodology used in RG-002 is given in Section 6.1 Figure 1. A comprehensive list of Features, Events and Processes (FEP) was developed during the IAEA project “SAFETY ASSESSMENT METHODOLOGIES FOR NEAR SURFACE DISPOSAL FACILITIES” (ISAM). For convenience this list is attached. The ISAM list can be considered, in the form of a checklist, as applicable and as appropriate, in the development of an interaction matrix.

THE ISAM FEP LIST IN CLASSIFICATION SCHEME ORDER

0 ASSESSMENT CONTEXT
0.01 Assessment endpoints
0.02 Timescales of concern
0.03 Spatial domain of concern
0.04 Plant/Facility/Operation assumptions
0.05 Future human action assumptions
0.06 Future human behaviour (target group) assumptions
0.07 Dose response assumptions
0.08 Assessment purpose
0.09 Regulatory requirements and exclusions
0.10 Model and data issues

1 EXTERNAL FACTORS
1.1 Plant/Facility/Operation ISSUES
1.1.01 Site investigation
1.1.02 Design, repository
1.1.03 Construction
1.1.04 Emplacement of wastes
1.1.05 Closure
1.1.06 Records and markers
1.1.07 Waste allocation
1.1.08 Quality control
1.1.09 Schedule and planning
1.1.10 Administrative control
1.1.11 Monitoring
1.1.12 Accidents and unplanned events
1.1.13 Retrievability

1.2 GEOLOGICAL PROCESSES AND EFFECTS
1.2.01 Orogeny and related tectonic processes at plate boundaries
1.2.02 Anorogenic and within-plate tectonic processes (Deformation, elastic, plastic and brittle)
1.2.03 Seismicity
1.2.04 Volcanic and magmatic activity
1.2.05 Metamorphism
1.2.06 Hydrothermal activity
1.2.07 Erosion and sedimentation
1.2.08 Diagenesis and pedogenesis
1.2.09 Salt diapirism and dissolution
1.2.10 Hydrological/hydrogeological response to geological changes

1.3 CLIMATIC PROCESSES AND EFFECTS
1.3.01 Climate change, global
1.3.02 Climate change, regional and local
1.3.03 Sea level change
1.3.04 Periglacial effects
1.3.05 Glacial and ice sheet effects, local
1.3.06 Warm climate effects (tropical and desert)

1.3.07 Hydrological/hydrogeological response to climate changes
1.3.08 Ecological response to climate changes
1.3.09 Human response to climate changes
1.3.10 Other geomorphological changes

1.4 FUTURE HUMAN ACTIONS
1.4.01 Human influences on climate
1.4.02 Motivation and knowledge issues (inadvertent/deliberate human actions)
1.4.03 Drilling activities (human intrusion)
1.4.04 Mining and other underground activities (human intrusion)
1.4.05 Un-intrusive site investigation
1.4.06 Surface excavations
1.4.07 Pollution
1.4.08 Site Development
1.4.09 Archaeology
1.4.10 Water management (wells, reservoirs, dams)
1.4.11 Social and institutional developments
1.4.12 Technological developments
1.4.13 Remedial actions
1.4.14 Explosions and crashes

2 ENVIRONMENTAL FACTORS
2.1 WASTES AND ENGINEERED FEATURES
2.1.01 Inventory, radionuclide and other material
2.1.02 Waste form materials, characteristics and degradation processes
2.1.03 Container materials, characteristics and degradation processes
2.1.04 Buffer/backfill materials, characteristics and degradation processes
2.1.05 Engineered barriers system, characteristics and degradation processes
2.1.06 Other engineered features materials, characteristics and degradation processes
2.1.07 Mechanical processes and conditions
2.1.08 Hydraulic/hydrogeological processes and conditions
2.1.09 Chemical/geochemical processes and conditions
2.1.10 Biological/biochemical processes and conditions
2.1.11 Thermal processes and conditions
2.1.12 Gas sources and effects
2.1.13 Radiation effects
2.1.14 Nuclear criticality
2.1.15 Extraneous materials

2.2 GEOLOGICAL ENVIRONMENT
2.2.01 Disturbed zone, host lithology
2.2.02 Host lithology
2.2.03 Lithological units, other
2.2.04 Discontinuities, large scale (in geosphere)
2.2.05 Contaminant transport path characteristics (in geosphere)
2.2.06 Mechanical processes and conditions (in geosphere)
2.2.07 Hydraulic/hydrogeological processes and conditions (in geosphere)
2.2.08 Chemical/geochemical processes and conditions (in geosphere)
2.2.09 Biological/biochemical processes and conditions (in geosphere)
2.2.10 Thermal processes and conditions (in geosphere)
2.2.11 Gas sources and effects (in geosphere)

2.2.12 Undetected features (in geosphere)
2.2.13 Geological resources

2.3 SURFACE ENVIRONMENT
2.3.01 Topography and morphology
2.3.02 Soil and sediment
2.3.03 Aquifers and water-bearing features, near surface
2.3.04 Lakes, rivers, streams and springs
2.3.05 Coastal features
2.3.06 Marine features
2.3.07 Atmosphere
2.3.08 Vegetation
2.3.09 Animal populations
2.3.10 Meteorology
2.3.11 Hydrological regime and water balance (near surface)
2.3.12 Erosion and deposition
2.3.13 Ecological/biological/microbial systems
2.3.14 Animal/plant presence leading to contamination

2.4 HUMAN BEHAVIOUR
2.4.01 Human characteristics (physiology, metabolism)
2.4.02 Adults, children, infants and other variations
2.4.03 Diet and fluid intake
2.4.04 Habits (non-diet-related behaviour)
2.4.05 Community characteristics
2.4.06 Food and water processing and preparation
2.4.07 Dwellings
2.4.08 Wild and natural land and water use
2.4.09 Rural and agricultural land and water use (incl. fisheries)
2.4.10 Urban and industrial land and water use
2.4.11 Leisure and other uses of environment

3 RADIONUCLIDE/CONTAMINANT FACTORS
3.1 CONTAMINANT CHARACTERISTICS
3.1.01 Radioactive decay and in-growth
3.1.02 Chemical/organic toxin stability
3.1.03 Inorganic solids/solutes
3.1.04 Volatiles and potential for volatility
3.1.05 Organics and potential for organic forms
3.1.06 Noble gases

3.2 CONTAMINANT RELEASE/MIGRATION FACTORS
3.2.01 Dissolution, precipitation and crystallisation, contaminant
3.2.02 Speciation and solubility, contaminant
3.2.03 Sorption/desorption processes, contaminant
3.2.04 Colloids, contaminant interactions and transport with
3.2.05 Chemical/complexing agents, effects on contaminant speciation/transport
3.2.06 Microbial/biological/plant-mediated processes, contaminant
3.2.07 Water-mediated transport of contaminants
3.2.08 Solid-mediated transport of contaminants
3.2.09 Gas-mediated transport of contaminants

3.2.10 Atmospheric transport of contaminants
3.2.11 Animal, plant and microbe mediated transport of contaminants
3.2.12 Human-action-mediated transport of contaminants
3.2.13 Food chains, uptake of contaminants in

3.3 EXPOSURE FACTORS

3.3.01 Drinking water, foodstuffs and drugs, contaminant concentrations in
3.3.02 Environmental media, contaminant concentrations in
3.3.03 Non-food products, contaminant concentrations in
3.3.04 Exposure modes
3.3.05 Dosimetry
3.3.06 Radiological toxicity/effects
3.3.07 Non-radiological toxicity/effects
3.3.08 Radon and radon daughter exposure

APPENDIX 5: SITE WATER BALANCE

The following items must be taken into consideration in terms of a detailed quantified site water balance:

1 Surface waters e.g. streams, lakes, wetlands and seepage points.
2 Mine waters e.g. underground water, service water, dolomitic water.
3 Process water e.g. metallurgical operations, sludge returns.
4 Seepage to groundwater compartments beneath area sources such as slimes dams and waste rock dumps.
5 Groundwater dewatering and recharge systems.
6 Interceptor trenches.
7 Runoff from disturbed and contaminated areas.
8 Direct surface discharge points off the site.
9 Groundwater seepage off the site.
10 Surface and groundwater off-site.
11. Storm-water.
12. Evaporation and return water dams.
13. Water exported off the site.
14. Other water uses e.g. gardens and domestic.
15. Water Board Water.

The resulting water balance must be fully quantified and presented in sketch plan form for the site. The water balance should characterize the site with regard to water movement between different areas and with measured values or "best estimates" of the quantities involved. Intermittent and suspected paths should also be included. If software is used to calculate the water balance, demonstration of code acceptance by relevant other stakeholders should be provided. Department of Water Affairs is required.