NATIONAL NUCLEAR REGULATOR

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

INTERIM REGULATORY GUIDE

SAFETY ASSESSMENT OF OCCUPATIONAL RADIATION HAZARDS FROM NORM FACILITIES AND ACTIVITIES

RG-0024

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Non-Restricted

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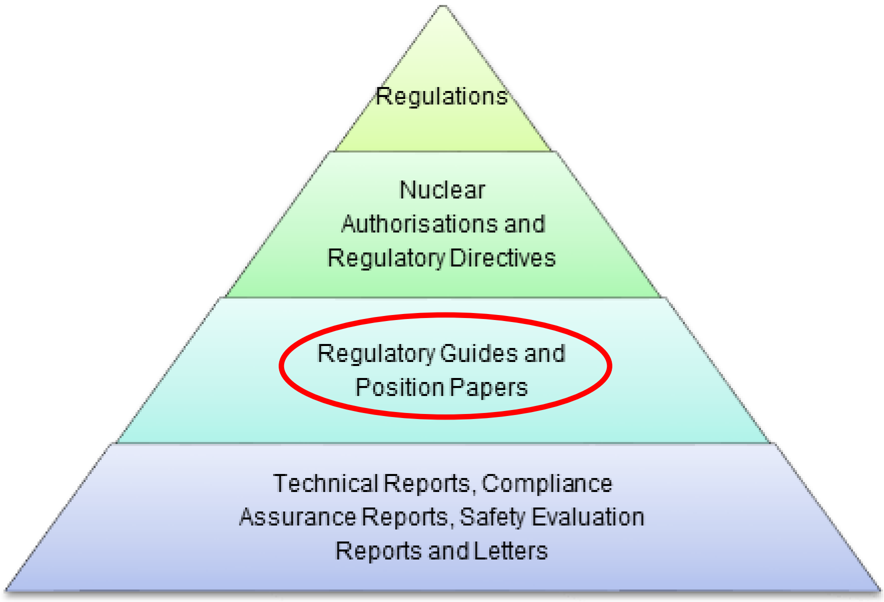

Figure 1: Location of the Regulatory Guide in the NNR Document Hierarchy

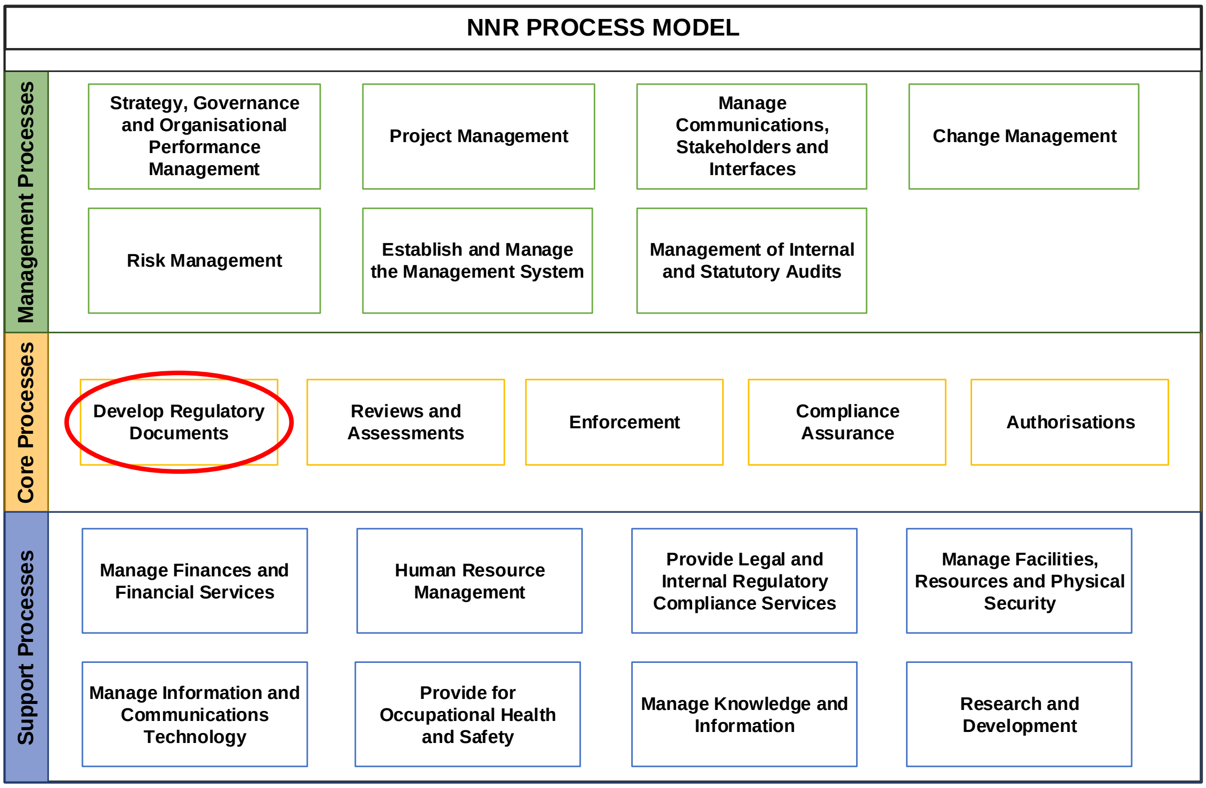

Figure 2: Location of the Regulatory Guide in the Process Model

FOREWORD

The legal framework applicable to regulation of nuclear industry in South Africa is comprised of law and supporting regulatory documents. Law includes legally enforceable instruments such as Acts, Regulations and Conditions of licences. Regulatory documents comprise of policies, standards, guides, notices, procedures and information documents which support and provide further information on the legally enforceable instruments. Both law and regulatory documents form the framework for regulation of the nuclear industry in South Africa.

Regulatory Guidance documents provide guidance to the licensees and applicants on how to meet requirements of the legally enforceable instruments. This Regulatory Guidance document provides more information about approaches used by National Nuclear Regulator for the Safety Assessment of Occupational Radiation Hazards from Norm Facilities and Activities.

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1 INTRODUCTION

(1) Radioactivity is a natural phenomenon and natural sources of radiation are features of the environment. Radiation and radioactive substances have many beneficial applications, ranging from power generation to uses in medicine, industry and agriculture. The radiation risks to workers and the public and to the environment that may arise from these applications have to be assessed and, if necessary, controlled. Activities must therefore be subject to standards of safety.

(2) The mining and processing of gold ore (with Uranium as a by-product), Thorium ore and other raw materials containing natural radionuclides are carried out in a number of facilities in South Africa. Activity concentrations of naturally occurring radionuclides are elevated in other mineral deposits such as heavy mineral sands and phosphate rock. Furthermore, high radon levels may be found in mines, irrespective of the activity concentrations of natural radionuclides in the raw material being extracted. Adequate radiation protection of workers is essential for the safe and acceptable use of radiation, radioactive materials and nuclear energy.

(3) Radiological Safety assessment is to be undertaken as a means of evaluating compliance with safety requirements for NORM facilities and activities and to determine the measures that need to be taken to ensure safety. The radiological safety assessments are to be carried out and documented by the organisation responsible for operating the facility or conducting the activity, are to be independently verified and are to be submitted to the Regulatory Body as part of the authorisation process. The implementation of these requirements is currently further supported by the following documents relating to radiological safety assessment of NORM facilities and activities:

a) LG-1012, “A license guide on the requirements for licensing users of small quantities of radioactive material; and
b) LG-1029 “licensing guide on the assessment of radiation hazards from surface operations to workers and visitors: Mining and Minerals processing

(4) This RG-0024 will supersede the regulatory documents listed above. This will only come into effect once the Draft Regulations are promulgated.

2 PURPOSE

Regulations are mandatory and provide specific requirements to be upheld by the authorisation holder and/or an applicant for a nuclear authorisation. This Regulatory Guide is developed to provide recommendations and guidance to authorisation holders and/or applicants on meeting the regulatory requirements on safety assessment of occupational radiation hazards associated with NORM facilities and activities.

3 SCOPE

(1) The provisions of this Regulatory Guide apply to the prior safety assessment, periodic safety assessment and operational safety assessment of radiation hazards to occupationally exposed persons from NORM facilities and activities for all stages of a facility or an activity where a safety assessment is needed taking graded approach into consideration. These provisions apply to all NORM facilities and activities such as but not limited to the following:

(a) Mining and Minerals Processing;
(b) Scrap Processing Facilities;
(c) Oil and Gas Industries (where applicable);
(d) Fertiliser Production and Phosphate Industries;
(e) Coal Mining Industries (where applicable);
(f) Refurbishers;
(g) Scrap Smelters;
(h) Service Providers;
(i) Small Users;
(j) Analytical Laboratories;
(k) Mineral Sands;
(l) Rare-Earths Processing Facilities;
(m) Water Treatment Facilities;
(n) NORM Waste Processing Facilities; and
(o) Any other NORM facilities and activities that may pose occupational radiation hazards

(2) Radiological safety assessment of exposures of the public to radiation hazards and assessment of non-radiological hazards are outside the scope of this Regulatory Guide.

4 DEFINITIONS AND ABBREVIATIONS

In this Regulatory Guide any word or expression to which a meaning has been assigned in the NNR Act or the Regulations promulgated in terms of the NNR Act, should have the meaning so assigned. Only additional terms, definitions and abbreviations are provided.

4.1 Definitions

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

Annual dose: The dose from external exposure in a year plus the committed dose from intakes of radionuclides in that year.

Anticipated operational occurrences: an operational process deviating from normal operation which is expected to occur at least once during the operating lifetime of a facility but which, in view of appropriate design provisions, does not cause any significant damage to items important to safety or lead to accident conditions;

Applicant: Any person or organisation applying to a regulatory body for authorisation (or approval) to undertake specified activities.
Strictly, an applicant would be such until the requested authorisation is either granted or refused.

Background Radiation: The *dose* or *dose rate* (or an observed measure related to the *dose* or *dose rate*) attributable to all *sources* other than the one(s) specified.
Strictly, this applies to measurements of *dose rate* or count rate from a sample, where the *background dose rate* or count rate must be subtracted from all measurements. However, *background* is used more generally, in any situation in which a particular *source* (or group of *sources*) is under consideration, to refer to the effects of other *sources*. It is also applied to quantities other than *doses* or *dose rates*, such as *activity concentrations* in environmental media
Becquerel (Bq): The SI unit of *activity*, equal to one (transformation) per second; supersedes the non-SI unit *curie (Ci)*. 1 Bq = 27 pCi (2.7×10^{-11} Ci) approximately; 1 Ci = 3.7×10^{10} Bq.

Committed dose: the lifetime dose expected to result from an intake.

Committed effective dose:the quantity E (τ), defined as:

$$E(\tau) = \sum_T w_T \cdot H_T(\tau)$$

where $H_T(\tau)$ is the committed equivalent dose to tissue T over the integration time τ and w_T is the tissue weighting factor for tissue T. When τ is not specified, it will be taken to be 50 years for adults and the time to age 70 years for intakes by children.

Committed equivalent dose: the quantity $H_T(\tau)$, defined as:

$$H_T(\tau) = \int_{t_0}^{t_0+\tau} \dot{H}_T(t)\, dt$$

where t_0 is the time of *intake*, $\dot{H}_T(t)$ is the *equivalent dose* rate at time *t* in organ or tissue T and τ is the time elapsed after an *intake* of radioactive substances. When τ is not specified, it will be taken to be 50 years for adults and to age 70 years for *intakes* by children

Contamination: the radioactive substances on surfaces, or within solids, liquids or gases (including the human body), where its presence is unintended or undesirable, or the process giving rise to its presence in such places. Contamination does not include residual radioactive material remaining at a site after the completion of decommissioning.

The presence of a radioactive substance on a surface in quantities in excess of 0.4 Bq/cm^2 for beta and gamma emitters and low toxicity alpha emitters, or 0.04 Bq/cm^2 for all other alpha emitters.

Decommissioning: Actions taken at the end of the useful life of a facility or activity, other than a repository or disposal facility, in retiring it from service with adequate regards for the health and safety of workers and members of the public and protection of the environment. Actions include shutdown, dismantling and decontamination, care and maintenance.

Dose rate: in relation to a place, the rate at which a person or part of a person would receive a dose of ionising radiation from external radiation if he were at that place being a dose rate at that place averaged over one minute.

Exposure: means the state or condition of being subject to irradiation.

External exposure: means exposure to radiation from a source outside the body.

Facilities and Activities: general term encompassing *nuclear facilities*, uses of all *sources* of *ionising radiation*, all *radioactive waste management activities*, *transport* of *radioactive material* and any other *practice* or circumstances in which people may be subject to exposure to *radiation* from naturally occurring or artificial *sources.*

Graded Approach: For a system of *control*, such as a regulatory system or a *safety system*, a *process* or method in which the stringency of the *control* measures and conditions to be applied is commensurate, to the extent practicable, with the likelihood and possible consequences of, and the level of *risk* associated with, a loss of *control*.

Long-lived alpha emitters: the natural radionuclides that decay predominantly via alpha radiation (α) in the ^{238}U, ^{235}U and ^{232}Th decay series which have half-lives comparable to the age of the earth such as ^{238}U, ^{234}U, ^{230}Th, ^{226}Ra, ^{232}Th, ^{228}Th and ^{235}U.

Nuclear Fuel Cycle: All operations associated with the production of nuclear energy, including mining, milling, processing and the enrichment of uranium or thorium; manufacture of nuclear fuel; operation of nuclear reactor; reprocessing of nuclear fuel; decommissioning; and any action for radioactive waste management and any research or development action related to any of the foregoing.

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

Radiation Risk: The detrimental health effects of exposure to radiation (including the likelihood of such effects occurring). Any other safety related risks (including those to the environment) that might arise as a direct consequence of exposure to radiation, the presence of radioactive material (including radioactive waste) or its release to the environment and a loss of control over a nuclear reactor core, nuclear reaction, radioactive source or any other source of radiation.

Radioactive material: any substance consisting of, or containing any **[radioactive nuclide]** radionuclide, whether natural or artificial [, including, but not limited to, radioactive waste and used spent nuclear fuel]

Radioactivity: the **[measure of a quantity of radioactive materials]** phenomenon whereby atoms undergo spontaneous random disintegration, usually accompanied by the emission of radiation.

Safety assessment: Assessment of all aspects of facilities and activities that are relevant to protection and safety; for an authorised facility, this includes siting, design and operation of the facility.

4.2 Abbreviations

IAEA	International Atomic Energy Agency
NNR	National Nuclear Regulator
NORM	Naturally Occurring Radioactive Material
RG	Regulatory Guide
LG	Licensing Guide
GSR	General Safety Requirements
ICRP	International Commission on Radiological Protection
SSRP	Safety Standards and Regulatory Practices

5 APPLICABLE LEGISLATION

The following specific regulations apply to facilities and activities involving NORM:

5.1 The current NNR regulations (Safety Standards and Regulatory Practices)
5.2 NNR draft regulations (General Nuclear Safety Regulations)
5.3 NNR draft regulations (Specific Nuclear Safety Regulations)

6 GRADED APPROACH TO SAFETY ASSESSMENT

1) Before starting the safety assessment, a judgement should be made as to the scope and level of detail of the safety assessment for the facility or activity, and the resources that need to be directed to it, and this has to be agreed with the regulatory body. The process should consider the following screening aspects:
   (a) The magnitude of the possible worker and public doses arising from the operation;
   (b) The possible level of optimisation for radiation protection;
   (c) The long-term impact of any residues on the environment in the case of disposal i.e. tailings storage facilities, water dams, etc.; and
   (d) The impact of residues containing NORM or contaminated materials that may be recycled;
2) A graded approach should be used in determining the scope and level of detail of the safety assessment carried out for a particular facility or activity, and the resources that need to be directed to it. The safety assessment should be consistent with the magnitude of the possible radiation risks arising from the facility or activity. For new facilities and activities, a prior safety assessment would apply since there will be no radiological information available. This should be updated once the facility or activity become operational and start handling radioactive material.
3) The approach should also take into account any releases of radioactive material in normal operation, the potential consequences of anticipated operational occurrences and possible accidents, and the possibility of the occurrences of very low probability events with potentially high consequences.
4) The complexity of the facility or activity should be taken into account by applying a graded approach to safety assessment. Complexity should relate to the extent and difficulty of the effort required to construct a facility or to implement an activity, the number of related processes for which control is necessary, the extent to which radioactive material has to be handled, the longevity of the radioactive material, and the reliability and complexity of systems and components, and their accessibility for maintenance, inspection, testing and repairs.
5) The level of analysis, verification, documentation, regulation, activities, procedures and resources used to comply with a safety requirement, should be commensurate with the potential hazard associated with the facility or activity or consequences if an activity is carried out incorrectly without adversely affecting safety.
6) A graded approach is applicable to all stages of the lifecycle of a facility or activity. During the lifetime of a facility or activity, any grading that is performed should be such that safety functions and operational limits and conditions are preserved, and such that there are no undue radiological hazards to workers, the public or the environment.
7) The application of the graded approach should be reassessed as the safety assessment progress and a better understanding is obtained of the radiation risks arising from the facility or activity. The scope and level of detail of the safety assessment should then be modified as necessary and the level of resources to be applied is adjusted.

7 OVERALL GUIDANCE

7.1 Scope of the Radiological Safety Assessment

1) The applicant or authorisation holder should indicate the scale and complexity of the operation or activities to be carried out, including:
   (a) Exploration;
   (b) Excavation and removal of ore;
   (c) Siting;
   (d) Construction;
   (e) Operation of facility or activity;
   (f) Decommissioning or closure of a mine or processing facility;
   (g) Secondary processing facilities; and
   (h) Any other phase of the facility or activity where NORM products or residues are considered likely to give rise to occupational exposures that are required to be controlled; or deemed appropriate
2) Stages that should be considered where applicable, in the lifetime of a Facility or Activity where a safety assessment is carried out, updated and used by the designers, the operating organisation and the regulatory body are:
   (a) Site evaluation for the facility or activity (Prospecting/ Exploration);
   (b) Development of the design;
   (c) Construction of the facility or implementation of the activity;
   (d) Commissioning of the facility or activity;
   (e) Commencement of operation of the facility or normal conduct of the activity;
   (f) Modification of the design or operation (including halting of normal activities);
   (g) Periodic safety reviews;
   (h) Decommissioning and dismantling of a facility or activity;
   (i) Closure of a repository for the disposal of radioactive waste and post-closure phase; and
   (j) Remediation of a site and release from regulatory control

7.2 Purpose of the Safety Assessment

1) The purpose of the safety assessment should be to identify operational activities (Sources of exposure) for which occupational radiation protection and safety measures require special attention i.e. quantitative analyses (pathways and dose estimation).
2) The safety assessment should address all radiation risks that arise from normal operation and from anticipated operational occurrences and accident conditions (in which failures or internal or external events have occurred that challenge the safety of the facility or activity). The safety assessment for anticipated operational occurrences and accident conditions also should address failures that might occur and the consequences of any failures.

8 PROCESS APPROACH

8.1 Preparation for the Safety Assessment

1) The first stage to carrying out the safety assessment should be to ensure that the necessary resources, information, data, analytical tools as well as safety criteria are identified and available.
2) Process description should be provided in the safety assessment to describe the activities and operations at a specific facility that could pose a radiation risk to the workers. The number of workers for each section or workplace should also be indicated in the assessment. The necessary preparations should be made to ensure that:
   (a) There are a sufficient number of people with the necessary skills and expertise available to carry out the work, i.e. Radiation protection and dosimetry; Ventilation (where appropriate, e.g. in underground mines); medical surveillance and Industrial safety; and adequate funding is available;
   (b) Background information is available relating to the location, design, construction, commissioning, operation, decommissioning and dismantling of the facility or activity, as relevant, together with any other evidence that is required to support the safety assessment;
   (c) The necessary tools for carrying out the safety assessment (i.e. radiation monitoring instrumentation and accredited laboratory for radionuclide analysis if the need arise) are available, including the necessary computer codes for carrying out safety analysis; and
   (d) The safety criteria approved by the Regulatory Body to be used for judging whether the safety of the facility or activity is adequate and risks have been identified.

8.2 Site Characterisation

(1) Site characterisation is defined as the detailed surface and subsurface investigations and activities at a site to determine the radiological conditions at the site or to evaluate candidate disposal sites to obtain information to determine the suitability of the site for a repository and to evaluate the long-term performance of a repository at the site.
(2) The scope and level of detail of the site characterisation should be consistent with:
   (a) The purpose of the assessment (e.g. to determine whether a new site is suitable for a facility or activity, to evaluate the safety of an existing site or to assess the long term suitability of a site for waste disposal)
   (b) The possible radiation risks associated with the facility or activity;
      (i) Dose Rates;
      (ii) Long-Lived Alpha Emitters;
      (iii) Radon (^{222}Rn), Thoron and Progeny (^{220}Rn and its decay products in the relevant decay series) Concentrations; and Surface Contamination (alpha and beta readings)

   (c) The type of facility to be operated or activity to be conducted; and

(d) The site characterisation should be reviewed periodically over the lifetime of the facility or activity (see Section 11).

(3) An assessment of the site characteristics relating to the safety of the facility or activity should cover:

(a) The physical, chemical and radiological characteristics that will affect the dispersion or migration or radioactive material released in normal operation or as a result of anticipated operational occurrences or accident conditions;

(b) Identification of natural and human induced external events in the region that have the potential to affect the safety of facilities and activities. This could include natural external events (such as, earthquakes for placement of tailings storage facilities and external flooding) and human induced events (such as hazards arising from transport where NORM is transported), depending on the possible radiation risks associated with the facilities and activities; and

(c) The history of the site or historical aspects of the site that can impact the facilities or activities such as footprints of previous metallurgical plants or tailings storage facilities or material buried on site.

(d) An assessment of the site characteristics relating to underground mining operations should cover:

(i) A description of the geology, type of mining, stoping methods, uranium grades and production statistics;

(ii) A description of the shaft including ventilation districts, main intakes, returns, number of working stopes, number of worked out stopes and description of basic ventilation methods and parameters such as ventilation rates;

(iii) The distribution of underground workers i.e. number of workers in different work categories; and

(iv) The occupancy factors of different work categories in different areas

8.3 Assessment of Radiological Exposure Pathways

(1) The exposure pathways for the sources present at the time of the survey must be addressed through comprehensive surveys of external gamma radiation, airborne radioactive dust, radon, thoron and their progenies, and surface contamination (alpha(α) and beta(β)) levels should be conducted to the following extent:

(a) Each working area should be surveyed, with particular attention paid to fixed working locations and to other areas where workers may remain for a large part of the day;

(b) The concentration of radioactive dust, its size distribution and the potential for its inhalation or ingestion should be stipulated;

(c) Measurements should be made of removable radioactive surface contamination on structures and equipment; and

(d) Radon concentrations in the air in underground workplaces should be measured.

(2) Taking the characteristics above into consideration, the pathways can be surmised as follow:
   (a) *Internal Exposures*
      (i) Inhalation of radon and thoron from NORM;
      (ii) Inhalation of radioactive dust from NORM; and
      (iii) Ingestion of food or water contaminated with NORM
   (b) *External Exposures*
      (i) Gamma and beta radiation source material
(3) Radon should be included in the occupational exposure determination where relevant. Additional considerations for radon specific provisions to be taken account of:
   (1) Radon is a unique radiation hazard, but is regulated in occupational exposure scenarios as the other external and internal radiation;
   (2) Applicants and authorisation holders should make use of available dose conversion factors/conventions to calculate the dose from radon to workers on the surface operations as well as for underground workers;
   (3) The dose conversions used to convert the radon exposure to dose; documented in ICRP Publication 65 [6] should be applied. ICRP has issued new conversion factors for radon in ICRP Publication 137 Occupational Intakes of Radionuclides: Part 3 [7]. The new dose coefficients (see Annex A for some examples) which upon adoption by the NNR, will come into force.
(4) As in the case of inhalation of radon
   (a) A description of a survey strategy and approach employed for each exposure pathway should be provided in the safety assessment report;
   (b) The number and location of measurements (GPS coordinates) should be included;
   (c) Sufficiently detailed plans of the underground areas identifying all survey locations should be included;
   (d) Line drawings should be of a reasonable quality to be acceptable; and
   (e) Where symbols are used, a key with an appropriate explanation should be indicated

8.4 Survey Strategies

(1) The extent of the survey should be sufficiently detailed to adequately determine the prevailing levels of the various hazards in the area under investigation and, in addition, to identify and quantify temporal variations.
(2) An area or facility should be divided into discrete sub-zones and survey these as discrete entities.
(3) In any survey, care should be taken to ensure that the survey technique is applied in a uniform manner to all areas to eliminate bias in the interpretation of results.
(4) For gamma radiation, the approaches that should be applied are:
   (a) The area should be divided into a grid pattern, measurements taken on contact with, and at one metre from, surfaces and the highest value in each grid square recorded;
   (b) A grid size of one square metre should be specified but deviations from this grid size may be justified due to, for example:
      (i) The extent of the area being investigated;

(ii) The low level of hazard; and
(iii) The low variability in the hazard

(c) An approach which is statistically valid should also be considered and may be acceptable as an alternative to the grid approach mentioned above

(5) For surface contamination, a grid pattern should be established to ensure a systematic and unbiased survey of surface contamination is carried out.

(6) For airborne contamination, the following are applicable:

(a) Due to the large amounts of loose materials handled in mining and minerals processing facilities and the localised extent and periodicity of airborne contamination, a statistically valid approach of full shift samples, over a period of time, should be necessary to adequately determine levels;

(b) For the initial surveys the following areas should, as a minimum, be covered over full shifts in respect of long lived alpha emitters:
(i) Areas close to open sources of dry materials;
(ii) Fixed working positions;
(iii) Open areas; and
(iv) Areas that are subject to splashing from wet process activities

(c) In respect of radon and thoron progeny:
(i) Poorly ventilated areas

(7) All measurement results should be included and listed in appropriate units e.g. µSv/h, Bq/m^3, µJ/m^3. Where measurements are expressed in WL units, the method of conversion to other units (e.g. µJ/m^3; mSv/a) should be included in the report.

8.5 Assessment of Engineering Aspects

(1) It should be determined in the safety assessment, if applicable, whether a facility or activity uses, to the extent practicable, structures, systems and components of robust and proven design. The following considerations should be applicable:

(a) Adequately designed and properly controlled ventilation systems are the most effective means of minimising the exposure to airborne radioactive substances in underground mines and in processing plants; and

(b) The first consideration in the design of facilities for the processing of raw materials should be the containment of the radioactive materials

8.6 Use of Computer Codes

(1) The applicant/authorisation holder should indicate which codes are used for modelling and be able to prove to the NNR that the controlling physical equations and data have been correctly translated into the computer code.

(2) On request of the NNR, the applicant or authorisation holder should provide the NNR with a Verification and Validation Report as per the regulatory guidance document RG – 0016 Guidance on the Verification and Validation of Evaluation and Calculation Models used in Safety and Design Analyses [9].

(3) If sensitivity or uncertainty analysis are performed using computer codes, the assessment should clearly state the purpose of the sensitivity or uncertainty

calculations and how single or multiple parameter analyses provide confidence in the assessment outcomes.

9 DOCUMENTATION OF THE SAFETY ASSESSMENT

(1) The results and findings of the safety assessment and the analyses that have been carried out for the purpose of demonstrating that the facility or activity is in compliance with the fundamental safety principles and the regulatory requirements, should be documented, as appropriate, in the form of a safety report that reflects the complexity of the facility or activity and the radiation risks associated with it.

(2) A Prior Safety Assessment should be submitted to the NNR with an application for a nuclear authorisation prior to siting, construction, operation, decontamination, decommissioning and closure of any nuclear installation.

10 INDEPENDENT VERIFICATION OF THE SAFETY ASSESSMENT

(1) The Authorisation holder should carry out an independent verification by a qualified expert such as a Radiation Protection Specialist (RPS) to increase the level of confidence in the safety assessment before it is applied by the operating organisation or submitted to the NNR.

(2) If the assessment was performed by the RPS, it would be advisable that a peer review be performed by another RPS and not the Radiation Protection Officer (RPO) or Radiation Protection Monitor (RPM) since this document would already be constituted at such a high level.

(3) It has to be determined in the independent verification whether the models and data used are accurate representations of the design and operation of the facility or the planning and conduct of the activity.

11 USE OF THE SAFETY ASSESSMENT

(1) The results of the safety assessment should be used to specify
    (a) The programme for maintenance;
    (b) Surveillance and inspection;
    (c) The procedures to be put in place for all operational activities significant to safety and for responding to anticipated operational occurrences and accidents; and
    (d) The necessary competences for the staff involved in the facility or activity and to make decisions in an integrated, risk informed approach

12 MAINTENANCE OF THE SAFETY ASSESSMENT

(1) The safety assessment is key to enabling the operating organisation to manage facilities and activities safely therefore it should be periodically reviewed and updated.

(2) The safety assessment should be submitted to the NNR for approval prior to commencing operations and at intervals specified in the nuclear authorisation.

(3) The safety assessment should establish the basis for all the operational safety-related programmes, limitations, design requirements and be commensurate with the nature of the operation and the radiation risks involved.

13 REFERENCES

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

[1] National Nuclear Regulator Act, (Act No. 47, 1999), (2015 revised edition)

[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] General Nuclear Safety Regulations (Section 36 of NNR Act) (2015 revised edition)

[4] International Atomic Energy Agency, *Safety Assessment for Facilities and Activities*, General Safety Requirements Part 4, No. GSR Part 4

[5] International Atomic Energy Agency, *Occupational Radiation Protection in the Mining and Processing of Raw Materials*, Safety Guide, No. RS-G-1.6

[6] ICRP, 1993. Protection Against Radon-222 at Home and at Work. ICRP Publication 65. Ann. ICRP 23 (2)

[7] ICRP, 2017. Occupational Intakes of Radionuclides: Part 3. ICRP Publication 137, Ann. ICRP 46(3-4).

[8] International Atomic Energy Agency, *Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards*, General Safety Requirements Part 3, No. GSR Part 3

[9] RG-0016 Guidance on the Verification and Validation of Evaluation and Calculation Models used in Safety and Design Analyses (2016)

14 ANNEX A: EXAMPLES OF ICRP 137 DOSE COEFFICIENTS FOR RADON EXPOSURE PATHWAYS (EXTRACT FROM ICRP PUBLICATION 137 [7])

1) Dosimetric Data for Radon

a) Ingestion of Radon Gas

The effective dose per intake of ingested ^{222}Rn is 6.9E-10 Sv per Bq.

Table 13.1 Effective dose coefficients following the inhalation of radon gas alone.

		Effective dose	
Nuclide	**Physical half-life, $t_{½}$**	**Sv Bq-1**	**mSv per Bq h m^{-3*}**
^{222}Rn (radon)	3.8 d	4.4E-10	1.8E-7
^{220}Rn (thoron)	56 s	1.8E-10	–
^{219}Rn (actinon)	4.0 s	4.8E-11	–

*This is the effective dose rate following chronic exposure to unit concentration of radon after the radon concentration in organs and tissues has reached saturation (i.e. equilibrium).

b) Inhalation of Radon Gas

The equilibrium effective dose rate for continuous chronic exposure to unit concentration of ^{222}Rn is 1.8E-7 Sv per Bq hm^{-3} (Table 13.1). In other words, this is the effective dose rate following chronic exposure to unit concentration of radon after the radon concentration in organs and tissues has reached saturation (i.e. equilibrium).

The effective dose coefficients in terms of Sv Bq^{-1} intake of radon gas are also given in Table 13.1. These values can be converted to effective dose per exposure (Sv per Bq h m^{-3}) by multiplying the Sv Bq^{-1} value by ($\lambda V_{RT\text{-}air}$.1/24), where λ is the transfer coefficient from the environment to RT-air (2600 d^{-1}) in the radon gas biokinetic model, and $V_{RT\text{-}air}$ (m^3) is the average volume of R_{Tair} (3.858 x 10^{-3} m^3 for an adult male).

c) Effective Dose Coefficients for Inhaled ^{222}Rn and ^{220}Rn Progeny

Table 13.2 provides values of effective dose for inhalation of ^{222}Rn gas with its short-lived progeny and ^{220}Rn progeny, expressed in units of mSv WLM^{-1}, mSv per mJ h m^{-3}, and mSv per Bq h m^{-3}.

Table 13.2 Effective doses from inhalation of radon and thoron in workplaces by a reference worker with an average breathing rate of 1.2 m^3h^{-1}.

			Effective dose per exposure¥		
Exposure/place*	**Unattached fraction, f_p**	**F**	**mSv per WLM**	**mSv per mJ h m^{-3}**	**mSv per Bq h m^{-3}**
Radon (^{222}Rn) gas + progeny					
Indoor workplace	0.08	0.4	20	5.7	1.3 x 10^{-5}
Mine	0.01	0.2	12	3.3	–
Tourist cave	0.15	0.4	24	6.7	1.5 x 10^{-5}
Thoron (^{220}Rn) progeny					
Indoor workplace	0.02	–	5.6	1.6	1.2 x $10^{-4‡}$
Mine	0.005	–	4.8	1.4	1.0 x $10^{-4‡}$

f_p, unattached fraction in terms of the potential alpha energy concentration; F, equilibrium factor.
¥For radon, 1 WLM = (6.37x10^5/F) Bqhm^{-3}; for thoron, 1 WLM=4.68x10^4 Bq h m^{-3} of equilibrium equivalent concentration of ^{220}Rn; 1 WLM = 3.54 mJ h m^{-3}.
‡In terms of mSv per Bq h m^{-3} of equilibrium equivalent concentration of ^{220}Rn.

2) Recommendations by ICRP

The present situation is a remarkable consistency between coefficients obtained by dosimetric calculations and conversion coefficients based on epidemiological comparisons. Noting that inhaled ^{222}Rn and progeny is a special case for which there is good epidemiology as well as dosimetry, and taking account of the two methods of calculation of dose coefficients with their associated uncertainties, the Commission recommends the following rounded dose coefficients.

For the calculation of doses following inhalation of radon and radon progeny in underground mines and in buildings, in most circumstances, the Commission recommends a dose coefficient of 3 mSv per mJ h m^{-3} (approximately 10 mSv WLM^{-1}). The Commission considers this dose coefficient to be applicable to the majority of circumstances with no adjustment for aerosol characteristics.

However, for indoor workplaces where workers are engaged in substantial physical activities, and for workers in tourist caves, the Commission recommends a dose coefficient of 6 mSv per mJ h m^{-3} (approximately 20 mSv WLM^{-1}).