DS427 Draft Version 4
Date: July, 2013

IAEA SAFETY STANDARDS

For protecting people and the environment

Status: STEP 7

First review by WASSC (lead), RASSC and NUSSC for approval for submission to Member States comments

Deadline for comments:

24 September 2013

Radiological Environmental Impact Assessment for Facilities and Activities

DRAFT SAFETY GUIDE **DS427**

FOREWORD

[Click here to insert foreword]

CONTENTS

1. INTRODUCTION 1

Background 1
Objective 2
Scope 2
Structure 4

2. EXPLANATION OF TERMS 5

Decision process 5
Authorization process (or Licensing process) 5
Environment and protection of the environment 5
Environmental Impact Assessment (EIA) 6
Radiological Environmental Impact Assessment (REIA) 6
Safety assessment 7

3. SAFETY OBJECTIVES AND REQUIREMENTS RELEVANT TO RADIOLOGICAL ENVIRONMENTAL IMPACT ASSESSMENTS 9

Responsibilites 9
Safety assessment 10
Graded approach 11
Public exposure and the impact to the environment 12
Potential exposures 12
Transboundary impacts 13

4. FRAMEWORK OF A RADIOLOGICAL ENVIRONMENTAL IMPACT ASSESSMENT (REIA) 15

5. METHODOLOGY FOR RADIOLOGICAL ENVIRONMENTAL IMPACT ASSESSMENT 19

Assessment of the impact of normal operations 20
Source term 21
Dispersion and transfer in the environment 22
Exposure pathways for members of the public 24
Identification of representative person for normal operations 25
Assessment of dose to representative person 25
Comparison of doses with constraint and limits 26
Exposure pathways for flora and fauna 27
Identification of representative organisms (flora and fauna) for normal operation 27
Assessment of dose rates to representative organisms 29
Comparison of dose rates with reference levels 30
Assessment of the impacts of potential EXPOSURES on humans 31
Potential exposure scenarios 32
Source term 33
Dispersion and environmental transfer 34
Exposure pathways to members of the public 36
Identification of representative person (for potential exposures) 36
Assessment of dose to representative person 37

Comparison of dose/risk with criteria 37
Variability and uncertainty in REIA 39

APPENDIX I. REFERENCE CRITERIA FOR CONSIDERATION OF POTENTIAL EXPOSURES 42

REFERENCES 45

ANNEX I. CONSIDERATIONS ON ASSESSMENTS OF RADIOLOGICAL IMPACT TO FLORA AND FAUNA 49

REFERENCES 53

ANNEX II. CONSIDERATIONS ON ASSESSMENT OF POTENTIAL EXPOSURES AND NATIONAL EXAMPLES 55

REFERENCES 63

CONTRIBUTORS TO DRAFTING AND REVIEW 65

1. INTRODUCTION

BACKGROUND

1.1. In 2011, the IAEA published the Safety Requirements: Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards, General Safety Requirements No. GSR Part 3 (BSS) [1]. These standards superseded the International Basic Safety Standards for Protection Against Ionizing Radiation and for the Safety of Radiation Sources issued in 1996 and are based on the IAEA's Fundamental Safety Principles [2], the updated recommendations of the International Commission on Radiological Protection (ICRP 103) [3] and on other relevant standards in the IAEA Safety Standards Series.

1.2. The requirement for the assessment of the radiological impacts to public and the environment as part of the safety assessment in the authorization process for facilities and activities[1] is identified as a requirement in the BSS. In this Safety Guide, this type of assessment is termed 'Radiological Environmental Impact Assessment' (REIA). The present Safety Guide interprets and elaborates on the requirement in the BSS for performing REIAs as part of the authorization process for facilities and activities; this requirement stems from Requirement 7 for notification and authorization namely: "Any person or organization applying for authorization: […] shall, as required by the regulatory body, have an appropriate prospective assessment made for radiological environmental impacts, commensurate with the radiation risks associated with the facility or activity." [1]

1.3. In the framework of international legal instruments or national laws and regulations, authorities may also require that, for some activities or facilities, a comprehensive initial evaluation of possible impact to the environment, including radiological impacts on members of the public and the environment is carried out. In this case, REIA is generally part of a broader 'environmental impact assessment' procedure which is generally named with the acronyms EIA and covers biophysical, social, economic and other relevant effects of development proposals prior to major decisions being taken. Within that framework, the results of this REIA may be used to inform judgements on the acceptability of such impacts, as defined by the radiation protection principles and criteria in the IAEA Safety Standards.

1.4. Therefore, REIA is related to, and may be part of, more comprehensive assessments used in the nuclear industry and other areas, namely safety assessment (SA) and EIA. The relationship between all these assessments is explored in this Safety Guide.

[1] Facilities and activities are defined in the IAEA Fundamental Safety Principles [2]: A general term encompassing nuclear facilities, uses of all sources of ionizing radiation, all radioactive waste management activities, transport of radioactive material and any other practice or circumstances in which people may be exposed to radiation from naturally occurring or artificial sources. Facilities include nuclear facilities, irradiation installations, mining and milling facilities, waste management facilities and any other place where radioactive materials are produced, processed, used, handled, stored or disposed of — or where radiation generators are installed — on such a scale that consideration of protection and safety is required. Activities include the production, use, import and export of radiation sources for industrial, research and medical purposes, the transport of radioactive material, the mining and processing of radioactive ores and closeout of associated facilities, clean up of sites affected by residues from past activities and radioactive waste management activities such as the discharge of effluents.

1.5. This Safety Guide presents and discusses approaches and methods to assess the level of radiological impact for planned exposure situations to members of the public and the environment, which are based on and consistent with the recommendations of the ICRP [3, 4, 5]. It is important to bear in mind that differently to the 'system of radiological protection of humans' adopted in the BSS, 'the system of radiological protection of the environment' and its practical implementation is still being developed by ICRP and the IAEA, respectively. Notwithstanding this consideration, the approaches given in this Safety Guide are to be considered adequate to carry out prospective assessment of the level of public and environmental radiological protection, as required in the BSS for planned exposure situation.

1.6. This Safety Guide is related to other guidance and reports published in the Safety Standards Series, Safety Report Series, and Technical Report Series, in particular to the safety guides on criteria for protection of the public and the environment against radiation exposure in planned exposure situations, emergency exposure situations and existing exposure situations [6, 52] and on regulatory control of radioactive releases to the environment [7]. This Safety Guide is supported by the IAEA safety report on methods and models to assess the impact of releases to the environment [8] and by IAEA technical reports like those on relevant environmental transfer parameter values [9, 10].

OBJECTIVE

1.7. The purpose of this document is to provide guidance on the implementation of requirements in the BSS for performing Radiological Environmental Impact Assessments (REIAs) for planned exposure situation as part of information provision, governmental decision-making and the regulatory authorization processes for facilities and activities.

1.8. This Safety Guide describes the contents of such assessments, their use and the procedures for their implementation as an aid to national regulatory bodies, persons or organizations applying for an authorization or responsible for the operation of facilities and activities in interpreting the requirements of the BSS and to other interested parties[2].

1.9. This Safety Guide should be useful to those preparing REIAs and those reviewing them, as part of a decision-making or authorization process. It may also be of relevance to different interested parties.

SCOPE

1.10. This Safety Guide provides guidance for the development of REIA in planned exposure situations, as described in the BSS. Planned exposure situations include expected exposures as a result of normal authorized discharges and also exposures that are not expected

[2] The term interested parties is used in the BSS to mean, in a broad sense, a person or group having an interest in the performance of an organization. Interested parties have typically included the following: customers, owners, operators, employees, suppliers, partners, trade unions; the regulated industry or professionals; scientific bodies; governmental agencies or regulatory bodies (national, regional and local) whose responsibilities may cover nuclear energy; the media; members of the public (individuals, community groups and interest groups); and other States, especially neighbouring States that have entered into agreements providing for an exchange of information concerning possible transboundary impacts, or States involved in the export or import of certain technologies or materials.

to occur with certainty, but might occur as a result of an event (that might be an incident or accident) or a sequence of events (i.e. potential exposures).

1.11. REIA as described within this Safety Guide is intended to be prospective in nature, for example, at the decision-making and authorization stages prior to siting, during construction and prior to operation, during operation (in the framework of periodic safety reviews) or prior to a decommissioning process. REIA should be also applied for those activities and facilities requesting changes in their operational processes, before the implementation of any change.

1.12. Notwithstanding the existence of similarities and a basic similar methodology, REIA described in this safety guide is not intended to assess retrospectively the radiological impact during operations or the consequences resulting from an accident. Nevertheless, the prospective assessment of potential exposures could provide preliminary information to be used in the assessments of consequences for planning of emergency response purposes.

1.13. REIA, as the prospective assessment of potential exposures in the framework of an authorization process, which would imply that accidents with low probabilities are considered and defined acceptance criteria are fulfilled, does not preclude the need for assessment of hazards associated with facilities, activities or sources to provide a basis for a graded approach to preparedness and response for a nuclear or radiological emergency in line with requirements in GSR Part 7 [54].

1.14. REIA, as described within this Safety Guide, could be an initial phase of hazard assessment for establishment of optimized protection strategy in potential emergency exposure situation and adequate emergency arrangements in line with requirements in GSR Part 7 [54]. However, the assessment of hazards associated with facilities, activities or sources in order to develop emergency plans does not substitute the regulatory requirement of the consideration and assessment of the potential exposures accidents could have.

1.15. This Safety Guide covers only radiological aspects for an environmental impact assessment. These include procedures to assess prospectively the radiological impacts on members of the public and to the environment, represented by flora and fauna. The particularities of the assessment of the radiological impact to the environment and potential exposures are discussed further in Section 5.

1.16. Some Member States may consider that the assessments of either doses to public or doses to public together with doses flora and fauna are sufficient to demonstrate radiological protection of the environment in a broader sense, for instance, that the environmental media and the natural resources are also protected based on the assumption that the low levels of radionuclides in the environmental media which are expected to fulfil the requirements for protection of humans or flora and fauna protection implicitly protect the other environmental components. Other Member States may require the more explicit inclusion of additional specific components of the environment, particularly in special situations, e.g. when particular natural resources, endangered species or specially designated protected areas — like nature reserves — are under consideration.

1.17. This Safety Guide does not cover the use of data from radiological environmental monitoring programs, which are normally undertaken at preoperational stages (for instance, to establish environmental activity concentration baselines) or during the operation of the facility and activity (with compliance objectives). Nevertheless, the development of REIA implies

that, during the operational stage, monitoring programs should be in place, in accordance with the requirements of the BSS, to ensure that the conditions assumed during the prospective assessments of the radiological impacts remain valid. In principle, the input data or the results of REIAs should not be straightforwardly compared with the operational data. This is because the actual discharges of an installation once in full operation, and consequently the resulting activity concentration in the environment may differ from those initially estimated in a conservative manner to make the prospective assessments. The IAEA provides guidance for source and environmental monitoring under the Safety Standards Series publications No. RS-G-1.8 [11]

1.18. The Safety Guide is limited to the radiological impact of a proposed activity on the public and the environment; i.e. it does not cover prospective occupational or medical exposures which should be addressed as part of the safety assessment during the licensing process and for which the IAEA has developed guidance [12, 13].

STRUCTURE

1.19. Section 2 gives definitions and explanations of the main concepts and terms used in the Safety Guide. Section 3 describes the safety objectives and requirements related to REIAs for governments, national regulatory bodies and licensees stemming from other IAEA standards and international conventions. Section 4 gives the framework in which REIA is being done. Finally, Section 5 describes the general methodology needed to carry out REIA for normal operations and potential exposures. Appendix I presents criteria which could be used for potential exposure considerations. Some consideration on flora and fauna radiological protection are discussed in Annex I and examples of national approaches to consider potential exposures to members of the public are presented in Annex II.

2. EXPLANATION OF TERMS

2.1. This section provides an explanation of some of the terms used within this Safety Guide. Because there may be different interpretations of some of the terms, the definitions explained here are solely for the purpose of this Safety Guide. While approaches may be in principle consistent with these concepts and terminology, the use of the terms defined in this section could differ from those used in Member States.

DECISION PROCESS

2.2. In the context of this Safety Guide the term decision process refers to the procedures carried out by the government or governmental agencies to decide whether an activity or a facility will be undertaken, continued or changed[3]. It could also apply to areas of national policy such as whether to embark on a nuclear power programme [14]. A formal decision process is normally conducted at the early stages of a programme of development and, mainly, for activities or facilities that are foreseen to need a thorough assessment of their potential impact to the environment.

AUTHORIZATION PROCESS (OR LICENSING PROCESS)

2.3. Authorization is a term defined in the BSS and is a formal procedure established in the national regulatory framework by which a regulatory body or other governmental body grants written permission, at different stages of the life of an installation or the development of an activity. The authorization, in the form of a registration or license [1], could be granted for design, siting, construction, operation and decommissioning activities. This Safety Guide covers the stages where prospective assessments of the radiological impacts to the environment are needed, such as during design, siting (including site survey and site evaluation), construction, pre-operation and pre-decommissioning. It also covers prospective assessments which may be conducted when an existing facility plan to change significantly its operational conditions, when major changes in the site characteristics affecting radiological conditions may arise or as part of a periodic safety review process for facilities and activities which already own an authorization, as required consistently with the BSS.

ENVIRONMENT AND PROTECTION OF THE ENVIRONMENT

2.4. The BSS [1] defines the environment as the conditions under which people, animals and plants live or develop and which sustain all life and development — especially such conditions as affected by human activities.

2.5. The Fundamental Safety Principles [2] states that the general intent of the measures taken for the purposes of environmental protection is to protect ecosystems against radiation exposure that would have adverse consequences for populations of a species.

[3] The term decision process proposed in this Safety Guide encompasses different terms used by the Member States with similar or equivalent meanings, such as ‘decision-making’, ‘decision-in-principle’ and in some cases ‘justification’ processes.

2.6. BSS specifies that the protection of the environment should include the protection and conservation of non-human species, both animal and plant, and their biodiversity; environmental goods and services such as the production of food and feed; resources used in agriculture, forestry, fisheries and tourism; amenities used in spiritual, cultural and recreational activities; media such as soil, sediments, water and air; and natural processes, e.g. carbon, nitrogen and water cycles[4].

2.7. The system of protection and safety described in the BSS [1] defines a framework to assess, manage and control exposure to radiation for humans which generally provides for appropriate protection of the environment from harmful effects of radiation. However, the BSS acknowledges that some national regulations may require the explicit demonstration (rather than the assumption) of the protection of the environment. The BSS also mentions that the assessment of impacts on the environment needs to be viewed in integrated manner with other features of the system of protection and safety and that the approach to the protection of people and the environment is not limited to the prevention of radiological effects on humans and on other species [1].

2.8. The BSS states that the protection of the environment is an issue necessitating assessment, allowing for flexibility in incorporating into decision making processes, the results of environmental assessments that are commensurate with the radiation risks. BSS establishes that the assessment of potential radiological environmental impacts should be undertaken in accordance with national requirements [1].

ENVIRONMENTAL IMPACT ASSESSMENT (EIA)

2.9. Environmental Impact Assessment (EIA) is not defined in the IAEA Safety Standards although it is included in many international instruments and national legislations and regulations [15, 16, 17, 18, 19, 20, 21, 22]. In the context of this Safety Guide EIA means a national procedure for evaluating the likely impact of a proposed activity on the environment, while impact refers to any effect caused by a proposed activity on the environment including human health and safety, flora, fauna, soil, air, water, climate, landscape and historical monuments or other physical structures or the interaction among these factors; it also includes effects on cultural heritage or socio-economic conditions resulting from alterations to those factors [5].

RADIOLOGICAL ENVIRONMENTAL IMPACT ASSESSMENT (REIA)

2.10. The requirement to assess potential radiological environmental impacts is identified in the BSS, but the term Radiological Environmental Impact Assessment (REIA) is not formally defined. For the purpose of this Safety Guide, REIA is taken to be a form of assessment that identifies the target(s), assesses the possible radiological impacts and compares the results with predefined criteria. It is a procedure for evaluating the likely radiological impact of a facility or activity on members of the public and the environment. Within this safety guide radiological impact is taken to mean the possible effects of radiation

[4] These processes may include biogeochemical cycles of other major elements.

[5] This general definition of EIA is adopted from the Convention on Environmental Impact Assessment in a Transboundary Context (Espoo Convention) [15] This definition can be used in a more general sense, not only in relation with transboundary impacts.

dose that may be caused by releases from a proposed facility or activity on human health and other elements in the environment, for example flora and fauna. REIA may be seen as one component of EIA in the context of planning for nuclear facilities. The numerical criteria presented in this safety guide are in the form of dose criteria or risk criteria related to a level of dose. Other non-radiological components of EIA might be thermal effects of discharges, environmental damages caused by chemical substances releases, disruption and environmental damage caused by facility construction and materials transport, and the visual detriment caused to the landscape by the proposed facility.

SAFETY ASSESSMENT

2.11. Safety Assessment (SA) is defined in the BSS [1] as "assessment of all aspects of a practice that are relevant to protection and safety; for an authorized facility, this includes siting, design and operation of the facility". In this context, practice is defined as any human activity that introduces additional sources of exposure (to radiation) or additional exposure pathways, or modifies the network of exposure pathways from existing sources, so as to increase the exposure or the likelihood of exposure of people or the number of people exposed.

2.12. This definition of SA is broad and all-encompassing and therefore, although radiological environmental impact assessment (REIA) is separately identified in the BSS, where it is relevant, SA can be considered to include REIA. REIA is one of the assessments which need to be considered in an environmental impact assessment (EIA) and consequently, REIA is also included in an EIA. It should be noted that REIA is not the only common element between SA and EIA; there are many other common items such as description of the environment, assessment for non-radiological environmental impacts including chemicals.

2.13. Non-radiological aspects such as the assessment of the physical impact of the construction of the facility on the environment may need to be included in an EIA. The EIA may also consider factors not directly related to safety, for example the social and economic impact, the impact on historic monuments and cultural places or the landscape. In turn REIA will be just one of the factors in the Safety Assessment[6] which is much broader in scope [14].

2.14. Figure 1 shows examples of the main elements listed for a Safety Assessment (based on IAEA Safety Guide GS G 4.1 [23]) and for an Environmental Impact Assessment (taken from the Espoo Convention [15]). Figure 1 is presented for illustrative purposes, to identify the common aspects of REIA in the different assessment frameworks; normally other elements not included in the figure are required to be specified.

[6] Specific Safety Guide SSG-12 [24] "Licensing Process for Nuclear Installations uses both the terms 'safety assessment' and 'environmental impact assessment' and discusses the important factors that should be assessed.

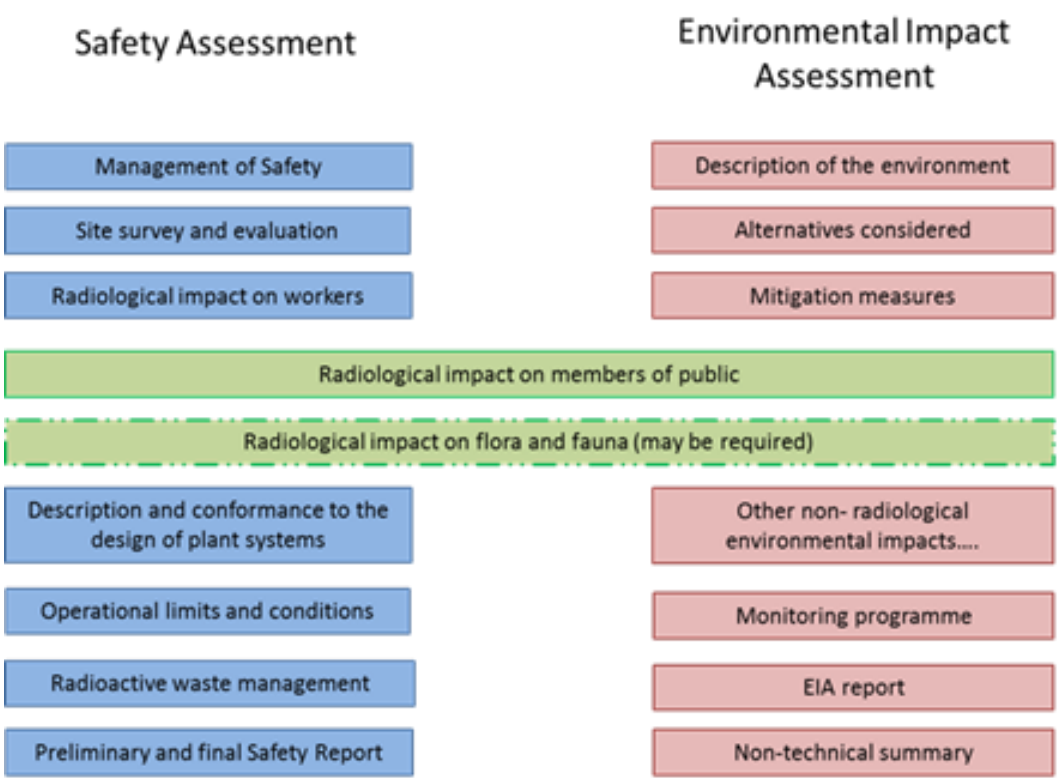

FIG. 1. Examples of elements in a Safety Assessment and in an Environmental Impact Assessment and illustration on how a Radiological Environmental Impact Assessment is common to both types of assessments.

3. SAFETY OBJECTIVES AND REQUIREMENTS RELEVANT TO RADIOLOGICAL ENVIRONMENTAL IMPACT ASSESSMENTS

3.1. The Fundamental Safety Principles [2] establishes, among others, principles for ensuring the protection of the public and the environment, now and in the future, from harmful effects of ionizing radiation. These principles apply to all situations involving exposure to, or the potential for exposure to, ionizing radiation. Under Principle 7 it states: "Whereas the effects of radiation exposure on human health are relatively well understood, albeit with uncertainties, the effects of radiation on the environment have been less thoroughly investigated. The present system of radiation protection generally provides appropriate protection of ecosystems in the human environment against harmful effects of radiation exposure. The general intent of the measures taken for the purposes of environmental protection has been to protect ecosystems against radiation exposure that would have adverse consequences for populations of a species (as distinct from individual organisms)".

3.2. Within this Safety Guide, it is assumed that the requirements on the establishment of a national regulatory infrastructure, as given in GSR Part 1 [25], have been fulfilled.

3.3. The BSS discusses the concepts and establishes requirements to the relevant interested parties (such as, government, regulatory body and operators) for the protection of people and the environment from harmful effects of ionizing radiation and for the safety of radiation sources. It also establishes requirements for conducting safety assessments using a graded approach. The details are discussed below.

3.4. GSR Part 4 [26] also documents the requirements for the safety assessment procedures which apply to facilities and activities.

3.5. The consideration of the protection the environment is contemplated in general in the IAEA Safety Standards [1, 2]. Where a specific link to the BSS cannot be made, this Safety Guide uses as a reference on environmental protection the IAEA Safety Guide DS432 [6], which is based on current recommendations, concepts and application framework for protection of biota made by the ICRP in publications [3, 5, 27, 28]. The use of the present guidance to consider explicitly protection of flora and fauna is subject to the national requirements.

3.6. The following paragraphs contain extracts from the IAEA Fundamental Safety Principles [2] and the relevant safety requirements in the IAEA Standards [1, 25, 26] reflecting the requisite to conduct REIA for planned exposure situations and its characteristics. It also gives links to the relevant sections within this Safety Guide which address these requirements.

RESPONSIBILITES

3.7. The BSS states that "any person or organization applying for authorization:

> (a)…Shall, as required by the regulatory body, have an appropriate prospective assessment made for radiological environmental impacts, commensurate with the radiation risks associated with the facility or activity" (para 3.8 in the BSS).

This is discussed in Section 4 which gives the context in which REIA is done and Section 5 which describes the methodology for a radiological environmental impact assessment.

3.8. Requirement 9 of the BSS (para 3.15 in the BSS) gives the responsibilities of registrants and licensees in planned exposure situations. It states that "registrants and licensees:

> (a)…Shall, for the sources for which they are authorized and for which the regulatory body requires an assessment to be made of the potential radiological environmental impacts, carry out such an assessment and keep it up to date".
>
> (b)…..Shall assess the likelihood and magnitude of potential exposures, their likely consequences and the number of persons who may be affected by them

These requirements are covered in Section 5 which describes the methodology for a radiological environmental impact assessment.

3.9. Requirement 12 of the BSS states that "the government or the regulatory body shall establish dose limits for… public exposure, and registrants and licensees shall apply these limits". Section 5 addresses this requirement.

3.10. Requirement 29 of the BSS, which relates to responsibilities specific to public exposure, states that "the government or regulatory body shall establish or approve constraints on dose and on risk to be used in the optimization of protection and safety for members of the public" (para 3.120 in the BSS). It states that "the regulatory body shall establish or approve operational limits and conditions relating to public exposure, including authorized limits for discharge. These operational limits and conditions:

> (a)…shall take into account the results of the assessment of the potential radiological environmental impacts undertaken in accordance with national requirements" (para 3.123 in the BSS).

The meaning of definitions and use of constraints on dose and risk are discussed in Section 5.

SAFETY ASSESSMENT

3.11. GSR Part 4 [26] establishes the generally applicable requirements to be fulfilled in safety assessment for facilities and activities, with special attention paid to quantitative analyses and the application of a graded approach to the ranges of facilities and of activities that are addressed. This is covered in Section 4.

3.12. The needs for safety assessments and REIAs are identified in paragraphs associated with Requirements 7 and 9 of the BSS. A more detailed specification of the contents of a safety assessment is set out in Requirement 13, Safety Assessment, and in the associated paragraphs. In those paragraphs, it is stated for example that "safety assessments shall:

> (a) identify the ways in which exposures could be incurred...'.

(b) ‘determine the expected magnitudes and likelihood of exposures in normal operation and, to the extent reasonable and practicable, make an assessment of potential exposures.[7]’

These requirements are addressed in Section 5 in paragraphs related to exposure pathways and to the methodology for assessing doses to members of the public from normal operations and potential exposures.

3.13. Associated paragraph 3.32 to BSS Requirement 13 *inter alia* states that “the safety assessment shall include, as appropriate, a systematic critical review of:

(a) The ways in which structures, systems and components… might fail… and the consequences of such events.”

(b) Any uncertainties or assumptions and their implications for protection and safety.”

This requirement is addressed the Section 5 when presenting the methodology for assessing doses to members of the public from potential exposures and under the considerations on uncertainty and variability.

GRADED APPROACH

3.14. Under Principle 5 of the Fundamental Safety Principles [2], it is stated that “the resources devoted to safety by the licensee and the scope and stringency of the regulations and their application, have to be commensurate with the magnitude of the possible radiation risks and their amenability to control” (para 3.24 in the SF). GSR 4 [26],

3.15. Requirement 1, states that to apply Principle 5 of the SF “a graded approach needs to be taken in carrying out the safety assessments for the wide range of facilities and activities … owing to the very different levels of possible radiation risks associated with them” (para 3.1 in GSR 4).

3.16. Requirement 6 of the BSS requires that the application of the requirements of these Standards in planned exposure situations shall be commensurate with the characteristics of the practice or the source within a practice, and with the magnitude and likelihood of the exposures.

3.17. Requirement 1 of GSR Part 4 [26] states that “other relevant factors, such as the maturity or complexity of the facility or activity, are also to be taken into account in a graded approach to safety assessment. It also states that “the application of the graded approach needs to be reassessed as the safety assessment progresses and a better understanding is obtained of the radiation risks arising from the facility or activity. The scope and level of detail of the

[7]The IAEA Safety Glossary [29] defines potential exposures as exposure that is not expected to occur with certainty but that may result from an accident at a source or owing to an event or sequence of events of a probabilistic nature, including equipment failures and operating errors. The BSS does not specify radiological criteria for potential exposures. This Safety Guide refers criteria for potential exposures from ICRP 64 [30] and INSAG [31] and discusses some options based on Member States experiences. More details on their meaning and application are given in Section 5, Appendix I and Annexes

safety assessment are then modified as necessary and the level of resources to be applied is adjusted accordingly."

The graded approach as applied to REIA is discussed further in Section 4.

PUBLIC EXPOSURE AND THE IMPACT TO THE ENVIRONMENT

3.18. More requirements related to REIA are contained under Requirement 31 of the BSS, Radioactive Waste and Discharges[8].

3.19. The BSS paragraph 3.132 *inter alia* states that "registrants and licensees, in cooperation with suppliers, in applying for an authorization for discharges, as appropriate:

(a) Shall determine the characteristics and activity of the material to be discharged, and the possible points and methods of discharge;
(b) Shall determine by an appropriate pre-operational study all significant exposure pathways by which discharged radionuclides could give rise to exposure of members of the public;
(c) Shall assess the doses to the representative person[9] due to the planned discharges;
(d) Shall consider the radiological environmental impacts in an integrated manner with features of the system of protection and safety, as required by the regulatory body (para 3.132 in the BSS)".

These elements are addressed in Section 5 which deals with the methodologies for carrying out REIA assessing doses to members of the public from normal operations and potential exposures.

POTENTIAL EXPOSURES

3.20. Requirements for the consideration of potential exposures which are established in the BSS were presented above under the title RESPONSIBILITIES.

3.21. GSR Part 4 [26] Requirement 6 states that "the possible radiation risks associated with the facility or activity shall be identified and assessed". This includes "the level and likelihood of radiation exposure of […] the public, and of the possible release of radioactive material to the environment, that are associated with anticipated operational occurrences or with accidents that lead to a loss of control over a nuclear reactor core, nuclear chain reaction, radioactive source or any other source of radiation".

Potential exposure is addressed in Section 5 and Appendix I of this Safety Guide.

---

[8] Some aspects of radiological environmental impact assessment in general are included in Requirement 31 in the BSS [1]. However, the main objective Requirement 31 is to establish authorized discharge limits. The procedure for establishing authorized discharge limits is not specifically addressed in this Safety Guide and it is discussed more fully in the IAEA's Safety Guide on Discharge Control [32].

[9] BSS define representative person as: An individual receiving a dose that is representative of the doses to the more highly exposed individuals in the population. ICRP Publication 101 [33] indicates that the dose to the representative person "is the equivalent of, and replaces, the mean dose in the 'critical group', and provides guidance on assessing doses to the representative person.

TRANSBOUNDARY IMPACTS

3.22. The BSS, in paragraphs associated to Requirement 29, addresses the issue of exposure outside the territory under the jurisdiction or control of the State in which the source is located[10]. It requires that "the government or the regulatory body:

> (a)…ensures that the assessment of the radiological impacts includes those impacts outside the territory or other area under the jurisdiction or control of the State.
>
> (b)…arranges with the affected State the means for exchange of information and consultations, as appropriate" (para 3.124 in the BSS).

This is discussed in Section 5.

[10] The consideration of the protection of the environment at the transboundary level and the obligations for assessing the impacts and sharing information between Member States should also be included within the broader context of relevant international agreements and conventions (e.g. UNCLOS 1982 [16], Espoo 1991 [15], Aarhus 1998 [17]) and Article 37 of the EURATOM Treaty [34]).

4. FRAMEWORK OF A RADIOLOGICAL ENVIRONMENTAL IMPACT ASSESSMENT (REIA)

4.1. The requirement of the application of the graded approach means that the scope and detail of REIA should commensurate with the magnitude and likelihood of the exposures, the possible radiation risks and the characteristics of the practice or the source within a practice.

4.2. REIA may vary increasing the details of the models and the input data to reflect the greater complexity of the exposure situation being assessed. For the sake of clarity, REIAs discussed in this Safety Guide are categorised as either simple or complex, although it is recognised that these terms are the two ends of the range of possible assessments and there are a large number of activities and facilities that should require an assessment falling between these two categories.

4.3. The national regulatory body should set the level of complexity of the assessments, taking into account the likelihood and magnitude of exposures, the characteristics of the facility and a number of additional factors. Examples of these factors and different elements that may be considered by the regulators are given in Table 1. Three of the factors relating to the characteristics of the facility are important to define the complexity of the assessment: the source term[11], the radionuclide inventory and the location of the facility. The scope and level of detail of the assessment may also vary depending on the stage in the authorization process; as this progresses, and a better understanding of the safety features of the facility or activity is required and improved data is obtained, the scope and level of detail should be modified as necessary. Other factors included in Table 1, which can be taken in consideration, are the number and characteristics of safety features, like engineering barriers (especially for potential exposures), and the level of interest in the relevant interested parties.

4.4. The list provided in Table 1 is not exhaustive and judgement made on the significance of these factors when selecting the type of REIA should be done by experts in nuclear and radiation safety and by national regulatory bodies. For example, availability of models and data required to run models play a part in the selection of the methodology.

4.5. Factors and elements in Table 1 are not ranked in order of importance and should be used as general guidance as to whether a simple or complex assessment might be appropriate. In principle REIA undertaken for the authorization of a nuclear power plant requires a high degree of complexity, while for a hospital operating a small nuclear medicine department a very detailed analysis may be not justified.

4.6. For facilities like hospitals or small laboratories it is likely that the authorization process will require only a one-phase safety assessment including REIA. This REIA may be based on relatively simple models using some generic data and cautious assumptions. For this type of installations there may be no requirement for an EIA, because significant impact to the environment is not expected even under accident scenarios. However, national regulatory bodies may establish their own requirements for activities or facilities which need an EIA.

[11]The amount and isotopic composition of material released (or postulated to be released) from a facility or during an activity involving radioactive materials, together with its physical and chemical properties relevant for environmental dispersion.

TABLE 1. EXAMPLES OF FACTORS AFFECTING THE REQUIRED COMPLEXITY OF ASSESSMENT

Factor	**Element**
Inventory	Form (chemical/physical make up)
	Radionuclides
	Quantity (both activity and mass/volume)
Source term	Potential for release source term varies between normal operation and potential exposure assessments
Level of expected dose (normal operations) or projected doses (potential exposures)	Previous similar facility or previous assessments
Location of facility	Presence of receptor
	Characteristics of environment around the facility
	Exposure pathways
Characteristics of authorization process for the particular activity or facility	Phase (decision process versus authorization process)
	Requirement of regulations (licensing requirements)
Safety characteristics of the activity or facility	Number of safety barriers and engineering features present in the design
Interested parties involvement	Degree of interest

4.7. For facilities like nuclear power plants and reprocessing facilities — there are likely to be a number of stages in the decision and authorization process. For example, there could be a need of an initial and final EIA and there might be different licenses granted for site selection, construction and operation, each requiring a different level of complexity in REIA. During the authorization process REIA should normally be revised to address any deficiencies in the data as the process of assessment and data acquisition progress, from site survey and site selection to preliminary safety assessment and then to final safety assessment. REIA at the early decision stage (e.g. in connection with an initial EIA) may be relatively descriptive in nature and based on generic data and conservative assumptions, whereas REIA included in the final Safety Assessment Report for the licensing process would need to consider more details in the modelling and site specific issues and improved data where possible. It should be considered that in the earlier stages of an assessment (e.g. in the initial EIA) generic REIAs for similar facilities already in operation in equivalent sites can provide useful information This is discussed further in Section 5.

4.8. Once the authorization or license have been granted, a periodic safety assessment review will be required (Requirement 24 of GSR Part 4 [26]) and this should include the review of REIA and a revision if necessary —for example if significant changes in the source term, in the characteristics of the operation and safety features of the activity or facility, or in the meteorological or hydrological data, or in the use of the environment has occurred).

4.9. Figure 2 is adapted from Figure 1 of IAEA Safety Standard SSG-12 on the licensing process for nuclear installations [24]; it shows where REIA with different characteristics might be carried out at different stages in the licensing process. Within this process, it could be necessary to perform REIAs with models of different levels of details but, in some cases, a single type of models for REIA could be used using as input the improved data resulting from the different stages. In each of the stages REIAs should constitute a hold points set by the regulatory body where the organizations responsible for the nuclear installation should ensure by mean of an assessment that the safety of public and environment is adequately assessed.

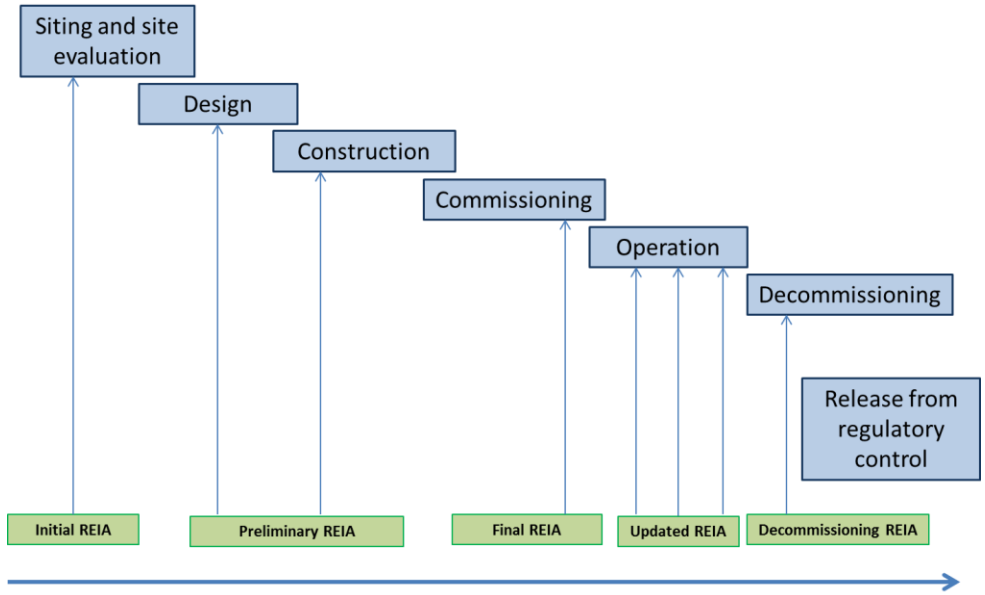

FIG. 2. Stages in the lifetime of a nuclear installation where REIAs might be input into the licensing process.

4.10. Governmental agencies or the regulatory body should establish mechanism to notify, consult and disseminate, as appropriate, the results of REIA to interested parties. REIAs are technical documents generally intended for people with expertise in radiation safety, from regulatory bodies, radiation protection technical support organizations, public health agencies, environment agencies. There may be a number of different interested parties which may not have a highly specialized expertise, for example, the general public, government departments and ministries not directly involved in radiation protection issues and other interested parties. REIAs should be well documented and transparent. There should be a section in the REIA report that explains the assessment in appropriate language that is understandable to all interested parties — for example a non-technical summary.

4.11. Where the results of REIA indicate that there could be possible impacts across national boundaries this information should be shared with the interested States.

4.12. The information used as basis for REIA could have commercial and security implications (for example, plans for the facility layout, information on accident sequences). This information should be available to only the regulatory authorities and other governmental agencies with the capacity to treat it confidentially. Normally the government in consultation with the national regulatory body and other relevant national organizations should establish which information should be made available publicly. The responsibility to ensure the validity of the restricted information should remain with the governmental agencies with functions related to safety and security. The restriction of access to certain sensitive information should be clearly explained so that it is not perceived by the interested parties as concealing information that is relevant for estimating and understanding the risk to people and the environment.

5. METHODOLOGY FOR RADIOLOGICAL ENVIRONMENTAL IMPACT ASSESSMENT

5.1. Since REIA within this Safety Guide is prospective in nature, reliance will have to be placed on mathematical modelling for evaluating, for example, the dispersion of radionuclides in the environment, transfer through environmental compartments, transfer to humans and to flora and fauna —as appropriate — and finally the radiation doses resulting from the associated external radiation or from the uptake of radionuclides by living organisms [8].

5.2. The models should be valid for the situation in which they are being applied. Where possible, the selected models should have been previously validated through comparison of their results with data for similar exposure scenarios or by mean of benchmarking procedures against other valid models. Section 1 also mentions the need for establishing environmental monitoring programmes for the operational phase of an activity or facility, to ensure that the conditions assumed in the prospective assessment remain valid.

5.3. Different methodologies, including calculation tools, can be used to carry out REIA [8]. The national regulatory body needs to be satisfied that the methodology adopted is adequate for the purposes of national practice and should decide — perhaps in discussion with the proposers of the facility or activity and other interested parties — which methodology is best suited to carry out REIA.

5.4. One consideration when deciding on the methodology that should be adopted is the amount of information that is required. A simple methodology requires less input data but may not provide very detailed results. On the other hand more complex methodologies may not be useful because the input data required cannot be obtained and the additional resources to obtain these data are not justified by the improvement in the results of the calculation carried out. An optimum trade off should be achieved between the amount of input data available and the details required.

5.5. For complex assessments the level of detail in the models and the data used for REIA will evolve during the decision and authorization process. The evolution in the models and data requirements for REIA during decision and authorization processes is further discussed in the following paragraphs.

5.6. REIA for planned exposure situations should consider expected exposures as a result of normal operations and also exposures that might occur as a result of potential situations (potential exposures). For this purpose, and according to the type of installations and national regulations, REIA may estimate:

(a) Doses to the public during normal operations;
(b) Doses or a measure of risk of health effects to the public from potential exposure scenarios;
(c) Dose rates to flora and fauna during normal operations;
(d) Dose rates to flora and fauna resulting from potential exposure scenarios.

The details and ways of use of the results of these estimations are discussed in the following sections.

5.7. Figure 3 gives the components of an assessment of the radiological impact from normal operations for both members of the public and flora and fauna. The first components of the assessment for both members of the public and flora and fauna require the same consideration. The first stage is to characterize the source of radiation related to the exposures; in the second stage dispersion in the environment and the transfer in the environmental compartments and the selected endpoints are considered. From this point onwards there are some differences in the details for the components of the assessment for members of the public and for flora and fauna.

5.8. The explicit assessment of radiological impact to flora and fauna during normal operations will depend on the characteristics of the activities and facilities under consideration and the requirements established in the national regulations. Some Member States may consider that the assessment of the radiological impact to members of the public would be sufficient to demonstrate protection of the wider environment. In that case, only the components on the left side would be considered (for this reason the line to exposure pathways to flora and fauna in Figure 2 is dashed). If the regulations in a Member State require the explicit assessment of the level of protection to flora and fauna, both branches of components should be considered.

5.9. In general, for activities or facilities requiring simple assessment the explicit consideration of the radiological impact to flora and fauna may not be necessary, on the basis that a significant radiological impact to the environment is not foreseeable due, for example, to the limited radionuclides inventories or the intrinsically safe characteristics.

5.10. In general terms, for members of the public, activity concentrations estimated in a number of environmental media are then combined with relevant habit data to calculate intakes of radionuclides (internal exposure) or external radiation (external exposure) to a representative person. The representative person is the hypothetical person representing those most likely to receive the highest doses. Intakes and external radiation are combined with dosimetric data to calculate doses to the representative person for comparison with dose constraints or limits or other relevant criteria. Similarly, for flora and fauna, activity concentrations in a number of environmental media are estimated and are then combined with available dosimetric data as well as information on the times spent in different habitats (for example, on soil, above soil, on the water, in the aquatic sediments, etc.) to estimate dose rates from internal and external exposures to representative organism. The representative organisms are the group of animals and plants representing those most likely to receive the highest exposures. The dose rates estimated can be compared with the reference levels.

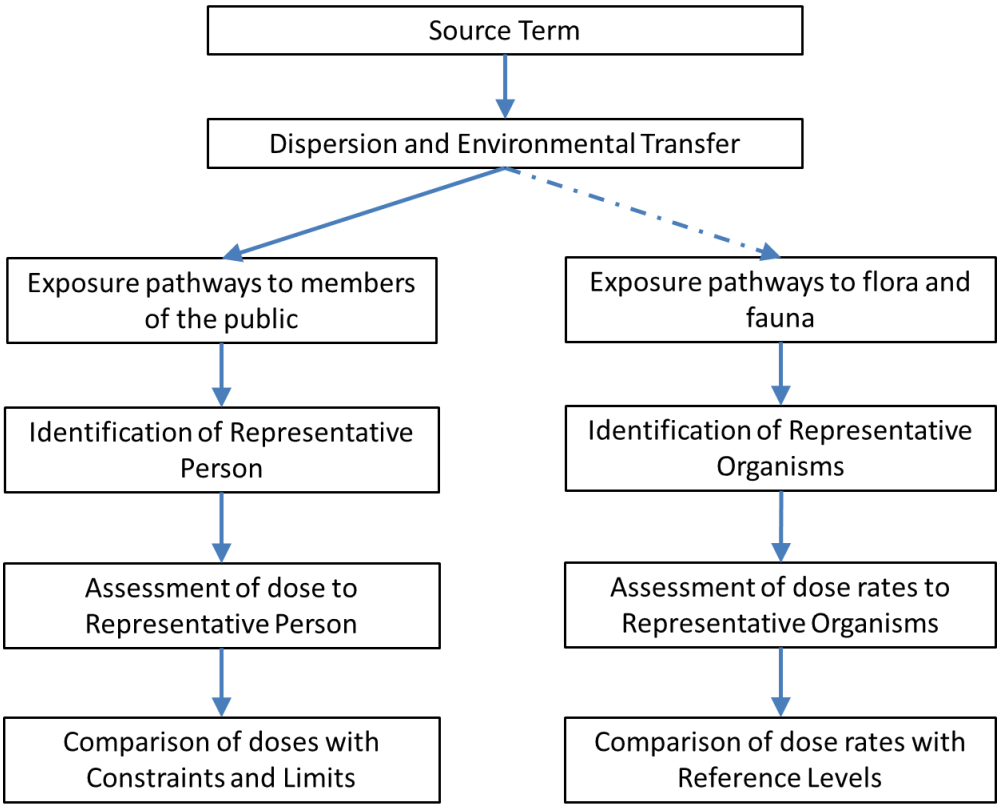

FIG. 3. Components of an assessment of radiological impact for normal operations.

5.11. The different components of the assessment are discussed in more detail in the following paragraphs. In line with Figure 3, the guidance presented in the paragraphs below on Source Term and Dispersion and Environmental Transfer applies to both members of the public and fauna and flora. For subsequent steps — e.g. Exposure pathways onwards — the approaches for members of the public and fauna and flora are presented separately.

Source term

5.12. The source term selected for REIA should be appropriate for the type of facility or activity being considered. All relevant radionuclides, from a radiological point of view, should be identified along with, if required by the national regulatory body, details of the mechanism leading to the release of these radionuclides. Releases to the atmosphere, to the aquatic environment and direct irradiation should be considered if appropriate. Other information that may need to be submitted, particularly for installations requiring complex assessments, includes the physical and the chemical attributes of the radionuclides released.

5.13. In some cases, for instance at the initial stages of an authorization or decision process, generic source terms for the proposed facility could be used, based on preliminary estimations, published data or on the experience from similar installations. Information on generic source terms for normal operation of nuclear reactors can be found in [35, 36]. Later, when the type of facility has been selected (e.g. the design and detailed characteristics of the nuclear power plant) and the possible sites have been identified or decided upon, the source term should be more accurately characterized by mean of appropriate safety analysis.

5.14. The total estimated releases should be provided over the period required by the regulatory body — this is generally a year of operation. REIAs will typically assume that the discharges are continuous and constant over a year. Where this is not the case and there is a significant variation in the discharges over a short time period, e.g. during special maintenance or refuelling of reactors or for typical iodine-131 discharges to sewer from thyroid treatment departments at a hospital, then short term releases will need to be assessed.

Dispersion and transfer in the environment

5.15. A variety of models and data are required to predict the dispersion and transfer of radionuclides through the environmental media and to the entities required for assessing internal and external doses to the selected endpoints (e.g. representative person and representative organism, as relevant). Activity concentrations in environmental media and components such as air, sediments, soil, water, animals and plants will need to be estimated. Environmental models to assess dispersion and transfers of varying levels of complexity have been developed in several countries [8, 37].

5.16. For simple assessments two possible approaches are: (i) 'no dilution' which assumes exposure to the activity concentrations in the effluents at the point of discharge, or (ii) a generic environmental methodology that takes account of dilution and dispersion of discharges into the environment. The regulatory body should define which can be considered as the appropriate approach considering the characteristics of the installations and the factors discussed in Section 4.

5.17. For complex assessments two possible approaches are (i) a generic environmental methodology (similar as that for the simple assessment) or (ii) a detailed environmental methodology —using, for example, site-specific data— to estimate activity concentrations in different environmental media. In these cases, models should be able to predict both spatial distribution and temporal variation of activity concentrations. The complexity of the model used should be commensurate with the possible environmental impact of the installation and should be defined by the regulatory body considering the factors discusses in Section 4.

5.18. For assessment of exposures to members of the public the dispersion and transfer models should be able to simulate, as necessary, at least the following processes:

(a) Atmospheric dispersion;
(b) Deposition of radionuclides on the ground or other surfaces;
(c) Dispersion of radionuclides in surface water and ground water;
(d) Transfer of radionuclides to plants and animals in the food chain

5.19. The dispersion and environmental transfer models for assessment of exposures to flora and fauna should be, in principle, similar to those used in the assessment of exposures to humans, considering the environmental media which is relevant to estimate exposures to flora and fauna. For example, they should be able to predict the activity concentrations in the relevant environmental media such as air, rivers, seawater, sediments and soil.

5.20. For installations requiring complex assessments, the models used to predict activity concentrations in the air, in the aquatic media and on the ground should take account of the physical-chemical properties of the radionuclides being released —like chemical form, particle size, caudal, flux velocity and temperature of the effluents— to assess, for example, the effective release height or the mixing length; the effects on the dispersion of effluents by

nearby buildings and the removal mechanism like wet and dry deposition as well as radioactive decay should be considered and included in the model capabilities.

5.21. For simple assessments the meteorological and hydrological conditions could be of a generic character based on bibliography or national records. The meteorological and hydrological conditions used for the complex assessments should be appropriate and specific for the site in question and should preferably be averaged from several years of data. Such data may be available for the site itself or from nearby meteorological or hydrological stations. Gaussian type dispersion models [8] can be used in general depending on the geographical characteristics of the sites under consideration. However, for more complex dispersion conditions, for example for installations located close to mountainous regions or places where complex local air circulations are expected, more complex dispersion models may be necessary. In any case, predictions of these dispersion models should be based on realistic though cautious assumptions. If the location of the facility is known these assumptions should take account of site-specific conditions.

5.22. Radionuclides may be discharged to a freshwater, estuarine or marine environment. There may also be discharges of radionuclides to the sewer system. Radionuclides discharged to water bodies are dispersed by general water movements and sedimentation processes. Much depends on the local characteristics of the receiving environment and it is not possible to have a totally generic model for these releases. For example, for rivers information is required at least on the size of the river and its flow rate. Models are required to predict the activity concentrations in water and in sediment. From these data activity concentrations in aquatic food, such as fish and crustaceans and aquatic flora and fauna, as relevant, can be estimated together with external radiation doses from exposure to sediments.

5.23. For some activities and facilities discharges of radioactive liquids to sewer systems may occur with the waste water being carried to sewage treatment works. When assessing discharges to sewers, it is necessary to model the transfer of the radionuclides to the sewage works and their subsequent release into the environment. Radionuclides could be discharged from the sewage works with the treated effluent, to rivers or coastal waters, where the models discussed above would be required. In addition, radionuclides may be associated with the sewage sludge which is disposed of in various ways including its use as a land treatment and disposal by incineration. Appropriate models are then required for the transfer of radionuclides through terrestrial food chains and for atmospheric releases.

5.24. When radionuclides are continuously discharged they accumulate in the environment up to the point where equilibrium conditions are reached. For long-lived radionuclides this accumulation may need to be considered in the assessments and taken the lifetime of the facility into account[12]. The concentrations of activity in the environmental media used to estimate doses should be that representative of the conditions when accumulation reaches to equilibrium.

5.25. A radionuclide may decay into a progeny that is also radioactive and this may need to be taken into account. In some cases, the decay products may be more radiologically significant than the parent and so it is important to consider the ingrowth. Examples of this are the uranium decay series and plutonium-241 which decays into americium-241. The

[12] For some radionuclides such as plutonium-239, which have long half-lives and are not chemically mobile it can take many decades before equilibrium is reached.

assumptions and approaches to deal with progeny, including the exclusion of progeny if applicable, should be justified.

5.26. The transfer of radionuclides from environmental media, like water, air and soil, to the plants and animals in the human food chain should be estimated using generic recommended transfer factors like those in IAEA publications [8, 9, 10, 38]. Transfer factors are given in those publications for food in the terrestrial, marine and freshwater ecosystems. If there is a need to improve the assessment, for instance when the initial estimated doses using generic transfer factors are above or close to the acceptance criteria, transfer factors based on site specific measurements could be necessary. The regulatory body should decide when site specific data based on measurements should be used in a REIA, bearing in mind that it might be impracticable or overlay costly. The uncertainties due to lack of site specific data on transfer parameters can be compensated with conservative assumptions, for example, in the habit data.

5.27. For installations requiring complex assessment, an initial estimation of the dispersion and transfer to the environment can be done using simple cautious models and meteorological/hydrological data generic to the region (from published data or from records from the closest meteorological/hydrological stations, which may sometimes be located at tens to hundreds of kilometres from the sites). Later, data from measurements conducted on-site or very close to the plant location would normally be available, as this is the regular practice during site survey and construction stages. Information on the type and detail of data which should be available at the later stages of licensing process can be found in IAEA publications [39, 40, 41].

5.28. From this point onwards there are some differences in the assessment methodologies between members of the public and flora and fauna (while the overall approach, i.e. to identify targets, assess doses and compare to a criteria, remains the same). The exposure pathways, representative persons or organism, characteristics of the dose assessments and definition and use of radiological criteria are described separately in the following text, firstly for members of the public and then for fauna and flora.

Exposure pathways for members of the public

5.29. Doses should be calculated for a number of exposure pathways which are considered relevant for the exposure situations associated with releases to the environment. An indicative list of exposure pathways for both internal and external exposures is given below:

For releases to atmosphere and surface waters during normal operation (typically, for nuclear power plants):

(a) Inhalation of radionuclides in an atmospheric plume;
(b) Ingestion of crops, animal food products (milk, meat);
(c) Ingestion of drinking water;
(d) Ingestion of aquatic food (freshwater or seawater fish, crustaceans, molluscs);
(e) External exposure from radionuclides in an atmospheric plume;
(f) External exposure from radionuclides deposited on ground;
(g) External exposure from radionuclides in water and sediments (e.g. from activities on shores, swimming, fishing etc.).

For releases to the sewage system during normal operation (typically for laboratories and hospitals):

(h) Inhalation of resuspended sewage sludge;
(i) External exposure from radionuclides in sewage sludge.

5.30. Not all the exposure pathways listed in paragraph above may need to be included in the assessment; the contribution of an exposure pathway to the overall dose depends on the radionuclides involved, the habit data and other characteristics of the population being considered. Therefore some exposure pathways may be excluded from the assessment on the grounds that the doses associated with certain pathway are negligible.

5.31. In some circumstances, it may only be possible to calculate doses for very general categories of food using generic values. For example doses can only be calculated for ingestion of crops, without being able to specify which types of crops these. However, if surveys have been made close to the site then it may be appropriate to use site specific values of the actual crops in the region.

5.32. It should also be noted that other exposure pathways may contribute to the dose received by individuals in particular circumstances, for example consumption of particular seafood for a short period of time.

Identification of representative person for normal operations

5.33. Dose should be calculated to a representative person using characteristics selected from a group of individuals representative of those more highly exposed in the population. ICRP Publication 101 [33] gives guidance on the characteristics of the representative person.

5.34. Habit data of the representative person should be habits typical of the population living in the region where the facility is located or of the country at large. Habit data used in a REIA can be obtained from statistics collected at national, regional or international level or, where possible, from surveys carried out at or near the location where the facility will operate. Habit data include consumption rates of food and drinking water, inhalation rates, location (e.g. distance and direction from the point of release) where people live and obtain their food, fraction of the food consumed that is of local origin, occupancy times (time spent at different locations) and time spent outdoors and indoors. Account should be taken of factors reducing the level of exposure, such as the degree of shielding or filtering offered by the buildings assumed to be inhabited. The representative person can be a hypothetical person or group of persons in a conservative location from the point of view of the exposure (e.g. close to the fence or in the regions where the highest deposition can be expected).

5.35. The characteristics of the representative person should be defined according to the national regulations and through a systematic process involving the regulator. For example, the regulatory body may require the use of more detailed and site specific habit data for REIAs carried out for certain types of facilities or at latter stages in the authorization process.

Assessment of dose to representative person

5.36. REIA generally calculates individual effective doses. The effective dose calculated in a REIA is the sum of the committed effective dose from intakes of radionuclides (by ingestion and inhalation) and effective dose from external irradiation [1, 3]. Doses from internal irradiation are calculated using dose coefficients from intakes of radionuclides by ingestion

and inhalation, which provide committed effective doses per unit activity of intake, expressed in units of Sv Bq^{-1}. Tabulated values of dose coefficients applicable for members of the public are available in a number of publications [1, 42]. In some cases equivalent dose for particular organs or tissues of interest may be required by the national regulatory body.

5.37. . Dose coefficients for internal irradiation are provided for different age groups [1, 42]. Generally, in REIA, doses should be calculated for adults. If there are factors that may result in a particular age group being more highly exposed than adults then these age groups should be considered. The application of dose coefficients for age groups should be weighed in relation to the ability to predict concentrations in the environment from a source and the ability to account for uncertainties in habit data for individuals exposed. Uncertainties in estimates of dose, particularly for prospective calculations, are generally not reduced significantly by increasing the number of age categories for which dose coefficients have been provided [33].

Comparison of doses with constraint and limits

5.38. The regulatory body should define a dose limit and a constraint for members of the public taking into account the requirements in the BSS.

5.39. The BSS defines an annual effective dose limit of 1mSv for members of the public. The effective dose limits specified in the BSS apply to the sum of the relevant doses from external exposure in the specified period and the relevant committed doses from intakes in the same period; the period for calculating the committed dose shall normally be 50 years for intakes by adults and up to age 70 years for intakes by children.

5.40. Dose constraints should take into account the characteristics of the site and of the facility or activity and the scenarios for exposure. The setting of the dose constraint needs to be considered in conjunction with other safety provisions and the technology available [1]. The dose constraint applies for a single source and should be set at a fraction of the dose limit, typically between 0.1 and 0.3 mSv in a year [32], and it is the relevant criterion when assessing doses to the representative person from normal operations.

5.41. Because dose constraints refers to a single source, the regulatory body should take account of the possible contribution to the individual doses of other sources, for example an installation located close or in the same site and, in that case, the proper reference criteria is the dose limit.

5.42. The national regulatory body may establish a reference level below the dose limit above which it may be necessary to refine the assessment. For example if estimates of the doses to the representative person are above a few tens of μSv per year, the assessment could be refined and, where appropriate more realistic assumptions made. However, sufficient caution should be retained in the assessments to provide confidence that actual doses received by members of the public will be below the dose limit.

5.43. A generic dose constraint (for example dose constraints for all nuclear fuel cycle facilities), which is normally defined by the national regulatory body, should be used at the initial phase of the assessment in the decision process (for instance, within an EIA). In the preliminary safety assessment stage, a source related dose constraint can be defined and

should be used as the acceptance criterion. Finally, in the final stages of the safety assessment when probably a process of optimization of the protection[13] has taken place, the acceptance criterion can be the dose corresponding to the authorized discharge limit. This is generally the dose corresponding to an optimized discharge level with a margin for flexibility of operations.

5.44. When considering transboundary impacts the acceptance criteria used for REIA should be the same for all countries being assessed.

Exposure pathways for flora and fauna

5.45. The exposures pathways that should be considered when assessing the radiological impacts on flora and fauna are:

(a) External exposure due to radioactive material in the atmosphere, water, soil and sediments;
(b) Internal exposure from incorporated radioactive material.

ICRP provides in publication [5] dosimetric factors for internal exposure and inmersion in water, soil planar and soil volume.

Identification of representative organisms (flora and fauna) for normal operation

5.46. ICRP has defined the concept of representative organism consistently with the concept of representative person [5]. Publication [28] indicates that representative organism is "a particular species or group of organisms selected during a site specific assessment, taking account of their assumed location with respect to the source". The actual choice of representative organism will depend upon the purpose of the assessment [5]. The manner representative organism are considered in this safety guide relates mainly to regulatory requirements on the prospective consideration of radiological impact to the environment of any proposed activity or facility.

5.47. The selection of representative organism to be used in a REIA could be based on assumptions of a generic character, site specific characteristics or be predetermined when, for example, some or a particular species are identified in a certain legislation. The regulatory body or the relevant governmental agency should endorse the definition of the representative organism to be used in a REIA.

5.48. In the more generic approach, representative types of animals and plants typical of the actual ecosystems of interest (terrestrial, freshwater or marine) could be selected that are appropriate for the kinds of environment and exposure scenarios under consideration. Based on ICRP Publication 108 [5], the animals and plants for exposure scenarios related to the terrestrial, freshwater and marine ecosystems, are presented in Table 2 below. In this generic assessment all the plants and animals in Table 2 related to the actual environments under consideration should be used as representative organism, irrespectively of the actual animals and plants in the area under consideration.

[13] As defined in IAEA Safety Glossary [29], the process of determining what level of protection and safety makes exposures, and the probability and magnitude of potential exposures, "as low as reasonably achievable, economic and social factors being taken into account" (ALARA).

TABLE 2. TYPES OF PLANTS AND ANIMALS FOR THREE MAJOR ECOSYSTEMS TO BE USED IN GENERIC ASSESMENTS OF RADIOLOGICAL IMPACT TO FLORA AND FAUNA

Ecosystem of interest	Types of plants and animals
Terrestrial	Large plant Small plant Insect Annelid Large mammal Small mammal
Freshwater	Aquatic Bird Amphibian Fish
Marine	Seaweed Crustacean Fish

5.49. In a more site specific approach, actual animals and plants could be identified and then related to one of the types of animals and plants of the respective ecosystems listed in Table 2. The representative organism would be based on those plants and animals in Table 2 which match with the site specific animals and plants under consideration.

5.50. In a predetermined assessment, the animals and plants of interest would be those previously identified in the legislations or regulations. Similarly to the site specific case, the predetermined animal or plant could be related to the types in Table 2 and this type of plant and animal should be used as the representative organism.

5.51. In all the cases discussed before, the location of the representative organism that is necessary to estimate the doses should be that which is representative of the highest exposure conditions for each of the plants and animals under consideration. It is important to note that, for the assessment of doses to animals and plants it is not necessary to define habit data for the plants and animals since, due to the way doses are estimated, the location is the only factor affecting the level of exposure. In view of the aim of radiological environmental protection, which in the case of flora is at the level of populations and not individuals, and the need to define a dose which can be considered characteristic of those more highly exposed, the dose should be averaged on a certain number of individuals or, for practical purposes, on a certain area.

5.52. In the generic approach, the group of representative organism most highly exposed should be assumed to be located in an area around the source — normally around the release point —where the highest environmental activity concentrations will typically occur[14]. The dose rates characteristic of this group should be estimated using the average activity concentration within this area. Although ecological characteristics around the release point may vary, in general areas surrounding the effluent release points in the order of 100–400 km^2 could be applied for most exposure scenarios relating to normal operation of activities or facilities.

[14] This assumption is based on the intrinsic properties of atmospheric and aquatic dispersion. This is discussed in Annex I.

5.53. In the site specific or predetermined approach, the location of the group of representative organisms should be related to the region occupied by the actual plants and animals of interest which are considered more highly exposed. In this case the activity concentration used to estimate exposures would be the value in that region averaged in an area of a size similar to that mentioned in previous paragraph.

5.54. The present methodology to assess radiological impact to the environment described in this Safety Guide uses types of animals and plants to define representative organism which are presented in Table 2. These types of animals and plants are based in the ICRP reference animals and plants (RAP) [5]. ICRP RAP is a set of hypothetical entities defined for the procedure of dose estimation and for considering the relation between doses and their effects for the purpose of radiation protection. The selection of the species, which may be used as indicators of the level of environmental protection, is discussed in [5], it is somewhat subjective and it is related to their connection with particular major ecosystems and, principally, to the existence of databases with information on radiation effects. For conducting REIA, as presented in this Safety Guide, the dosimetric factors to assess doses to the representative organism should be those published by ICRP in [5], for the corresponding RAPs, as illustrated in Table 3 below.

5.55. The approach presented in this Safety Guide may not be appropriate for the assessment of the impact to flora and fauna in certain particular ecological circumstances, for example when dealing with particular protected species, special ecological niches are identified or protected areas are defined. The particular situations needing special consideration should be discussed among the responsible of conducting the REIA and the national regulator or the competent governmental agency.

Assessment of dose rates to representative organisms

5.56. While for humans the dose quantity used for comparison with the dose criteria is the effective dose, for flora and fauna the relevant quantity to be used is the absorbed dose rate [15] [5].

5.57. Doses rates due to exposure via internal and external pathways should be calculated for the representative organisms. The absorbed dose rate could generally be estimated by using radionuclides media/biota transfer models based on concentration factors, the corresponding dosimetric factors and the times spent in different habitats. For the estimation of doses rates to the representative organism dosimetric factors and times spent in different habitats presented in [5] should be used. IAEA [10] and ICRP [43] provide concentration ratios for different flora and fauna, including the RAP.

[15] Radiation quality factors, like those used for the radiological impact assessment to humans (resulting in effective doses expressed in Sv) are not applied to assess impact to biota; the key quantity for the exposure assessment of biota is the absorbed dose, which is defined as the amount of energy that is absorbed by a unit mass of tissue of an organ or organism, given in units of Joules per kilogram or Gray (Gy) [8, 17]. Due to the consideration of different species of flora and fauna, with different life spans, it is convenient to express the reference criteria in terms of a dose rate, in Gy per day (or its adequate subunit, for instance mGy/d) [5, 44].

TABLE 3. DERIVED CONSIDERATION REFERENCE LEVELS FOR TYPES OF ANIMALS AND PLANTS TYPICAL OF MAJOR ECOSYSTEMS

Types of plants and animals	Equivalent ICRP RAP	Dose rate [mGy d^{-1}]
Terrestrial Ecosystem		
Large plant	Reference Pine tree	0.1–1
Small plant	Reference Wild grass	1–10
Insect	Reference Bee	10–100
Annelid	Reference Earthworm	0.1–1
Large mammal	Reference Deer	0.1–1
Small mammal	Reference Rat	1–10
Freshwater Ecosystem		
Aquatic Bird	Reference Duck	0.1–1
Amphibian	Reference Frog	10–100
Fish	Reference Trout	1–10
Marine Ecosystems		
Seaweed	Reference Brown seaweed	1–10
Crustacean	Reference Crab	10–100
Fish	Reference Flatfish	1–10

Comparison of dose rates with reference levels

5.58. ICRP [5] has defined a set of dose rate bands, referred to as derived consideration reference levels (DCRLs). DCRLs bands span an order of magnitude, within which there is likely to be some chance of deleterious effects of ionizing radiation to individuals of flora and fauna which may have implications in the structures or populations[16]. For dose rates below the base of DCRL bands, no effects have been observed or no information reported. DCRLs have been defined on the basis of radiation effects observed for species corresponding to the RAP. ICRP DCRLs should be used as criteria for comparison with the estimated dose rates to representative organism. The reference levels for the types of plants and animals used to define representative organisms, based on ICRP DCRLs are presented in Table 3 below. The Table also shows the corresponding RAP used by ICRP to model the dosimetry and relate doses to the database on effects.

5.59. The DCRLs do not represent limits; they should be considered as points of reference to inform on the appropriate level of effort that should be expended on environmental protection, dependent on the overall management objectives, the exposure situation, the actual fauna and flora present, and the numbers of individuals thus exposed [28].

5.60. If the dose rates to the representative organism are below the lower boundary of the relevant DCRL impact on population of flora and fauna could be considered negligible and no further actions are required. In the case where the estimated dose rates are in the middle in the bands the regulatory body could decide whether additional considerations or protection measures would be needed, bearing in mind that DRCLs are reference points, not limits. If the resulting doses are above the upper boundary of the relevant DCRL band, it implies a stronger need to consider more control on the source or further protection efforts.

[16] In some Member States, reference levels and methods for assessing the radiological impacts on flora and fauna have been developed that are generally consistent with the ICRP approach and, in some cases, could be established in national guidance or regulations.

ASSESSMENT OF THE IMPACTS OF POTENTIAL EXPOSURES ON HUMANS

5.61. One of the main objectives in considering potential exposures in REIA is to estimate the health effects (stochastic effects and deterministic effects) [1, 29] on individuals who are representative of the persons likely to be most exposed due to radioactive releases resulting from scenarios for potential events with low probability and large consequences. This section of the Safety Guide is focused on radiological impacts on individuals arising from potential exposures. States might include in their regulations the requirement to assess individual and societal impacts and risks of other kinds [24, 45]. The process for assessing impacts and risks of other kinds than radiological has aspects in common with the process described in the following paragraphs.

5.62. In the process of assessing potential exposures associated with facilities necessitating complex assessments, safety analysis techniques should be applied that consider elements such as anticipated operational occurrences, design basis accidents, beyond design basis accidents and other plant states, including severe accidents and design extension conditions [26, 47]. This Safety Guide does not discuss in detail the specifications and processes for the identification of these elements or the methodology for selection and analysis of types of abnormal occurrences or accident conditions. Such specifications and processes for analysis are discussed in detail in Safety Guide No. NS-G-1.2 [13] and in other related publications in the IAEA Safety Standards Series. In all cases, the specifications and the methodologies to be used are subject to national regulations and guidance on safety analysis. For the purposes of this Safety Guide, the expression 'potential accident scenarios' is used to include all the hypothetical abnormal accidents, events or sequences of events that would arise in a detailed safety analysis made on the basis of the characteristics of the facilities or activities concerned.

5.63. The identification and selection of potential exposure scenarios for facilities necessitating simple assessments is usually a more straightforward process. It could include the consideration of typical industrial accidents or events leading to environmental releases, such as fires and spillage, and other inadvertent unexpected releases.

5.64. The likelihood of accidents and assessment of the associated potential impacts is a probabilistic matter. The assessment of potential exposures involves specification of the scenarios that need to be considered. These scenarios can be specified in different ways, such as by selecting a single conservative accident[17], by identifying a set of characteristic accidents[18] or by identifying accident sequences from a broad range of initiating events by means of a methodological approach[19]. In the two latter cases the frequency or likelihood of

[17] A single conservative accident is an accident specified using what is assumed to be a bounding set of failure conditions that may be recognized as representative of a worst case accidental scenario. This type of assessment is sometimes termed a 'deterministic assessment'; however, it is clear that the potential exposure situation and its consequences have associated probabilities.

[18] Characteristic accidents are accidents that, as a result of the safety assessment, can be considered to be a comprehensive representation of the safety characteristics of the facility. The accidents identified as characteristics can be divided into different categories in accordance with their annual frequency or likelihood of occurrence and their consequences. Characteristic accidents do not necessarily include the worst case scenario which tends to be an over-conservative assumption leading to unrealistic potential consequences. (For further information see Annex II).

[19] A methodological approach to identifying accident sequences that can follow from a broad range of initiating events and that include a systematic determination of accident frequencies and consequences is known as Probabilistic Safety Analysis (PSA). Techniques of probabilistic safety analysis are normally applied to facilities

occurrence is taken into account. The end point in the first case is generally a hypothetical dose to members of the public due to a conservatively defined accident scenario, while for the latter it could be a either a dose or a quantity that provides a measure of the risk of health effects (see Appendix I). The option selected to specify the potential exposure scenarios to be used for the REIA should be taken into account in specifying and comparing with the reference criteria. Annex II provides examples from different Member States of the consideration of potential exposures.

5.65. Figure 4 shows the components of an assessment of the possible radiological impacts of potential exposures. This process can be carried out for a single potential accident or event; for a small set of conservative or characteristic potential accidents or events; or for a larger set of selected potential accident or event scenarios combined with their probabilities.

5.66. In general terms, the first step in a process to consider potential exposures should be to identify conceivable potential events. Next, the related source terms, including quantities and relevant physical and chemical characteristics of the emissions, should be estimated. Environmental dispersion and transfer should then be considered. The relevant exposure pathways should then be identified. The representative person (or persons) exposed due to the releases associated with the potential exposure should next be selected. Finally, the dose, or a measure of the risk of health effects, should be assessed and compared with the applicable established criteria. Each of the steps in Figure 4 is discussed below in more detail.

Potential exposure scenarios

5.67. For those facilities necessitating a simple assessment, for example hospitals and small laboratories, a single or a reduced number of conservative potential exposure scenarios involving a large proportion of the total inventories of radioactive material can be selected[20]. The inventory for these facilities is normally limited and well known. If the inventory varies with time — if, for example, some radioactive material is used or decays or is transferred from the facility — the maximum quantity that would normally be expected to be present at any one time should be assumed. In facilities of this type, accidents or events could arise in different ways; however, fires or large accidental spills will probably be the most important potential exposure scenarios to be considered.

5.68. For facilities necessitating complex assessments — such as nuclear power plants, large research reactors, radioisotope production facilities, waste management facilities, near surface waste disposal facilities and nuclear fuel reprocessing plants — a greater number of potential exposure scenarios may need to be considered. Since the source terms could be higher and the facilities have more complex technological features, the identification and analysis of potential exposure scenarios may need to be carried out in greater detail. For these assessments, complex safety assessment techniques, for example probabilistic safety analysis, should be used[21].

---

necessitating complex assessments, such as nuclear power plants, but they could also be applied to simple facilities. More information is provided in [47].

[20] The IAEA has developed extensive guidance to assist in safety assessment of potential severe accidents for radioactive sources [56].

[21] The IAEA has developed extensive guidance to assist in identifying initiating events of various types for potential exposure scenarios for nuclear power plants and other types of nuclear facility [48].

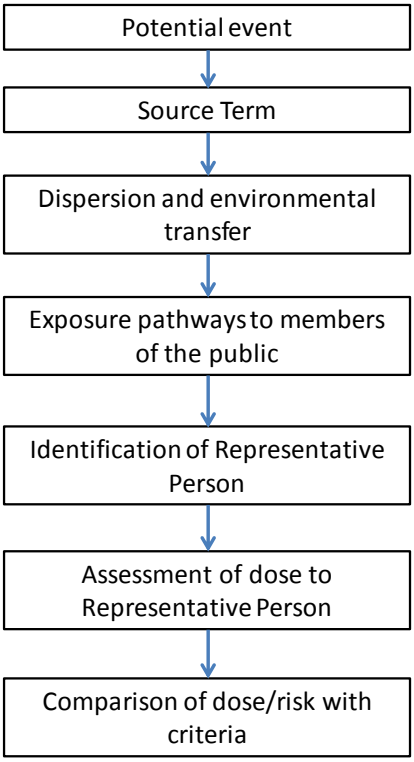

FIG. 4. Components of an assessment for potential exposures.

Source term

5.69. The different options for assessing potential exposures are based on the selection of adequately representative source terms[22]. Source terms should be estimated by considering the range of unexpected releases and by using simple or complex techniques normally applied in the safety assessment of facilities and activities, as required by their technological complexity.

5.70. For facilities necessitating simple assessments, as an initial step, it could be assumed that the entire inventory of radioactive material is released, and the radiological impacts of such a release are then analysed. In general, this is applicable if the related facilities or activities have relatively small inventories, such as hospitals or research facilities. If the source term for this maximized potential exposure scenario leads to estimated doses that are below the reference criteria established by the regulatory body, then no further assessment may be needed. If the reference criteria are exceeded, a more realistic release fraction should be used. However, in this case, the assumptions made should be justified, for example by means of simple engineering assessments to demonstrate that the source terms are more realistic than that obtained with the simple conservative assumptions and that they are not underestimates.

[22] The details of the process for the identification and selection of potential exposure scenarios and their associated source terms and, when applicable, the associated probabilities are not covered in this Safety Guide. Only general characteristics of the processes for selecting source terms that are relevant for the assessment and for comparison with the criteria are discussed here. For applying this Safety Guide for the purpose of conducting an REIA, it is assumed that adequate information on the source term is provided.

5.71. For facilities necessitating complex assessments, if the source term could be limited by the characteristics of the source (for instance, in the case of sources with physical properties that impede releases of large fractions of the inventory to the environment, even under accident conditions), initially a conservative source term could be used for the analysis. In order to determine the conservative source term, bounding assumptions should be used where necessary, and engineering analysis should be used where possible. If with this conservative source term the reference levels are exceeded, a more realistic estimate should be obtained on the basis of detailed safety analysis techniques.

5.72. For facilities, such as nuclear power plants, large research reactors, waste management facilities and nuclear fuel reprocessing plants, which have large inventories and where the physical, chemical or nuclear characteristics may facilitate large emissions in potential accident scenarios, detailed safety analysis techniques should always be applied to estimate realistic potential source terms. Further guidance on accidental source term estimations could be found in [49].

5.73. In estimating more realistic source terms, consideration may need to be given to the physical and chemical processes occurring during the accident sequence, the behaviour of any safety systems or the effects of any mitigation measures, and the behaviour and movement of any radioactive material in the facility before it is released off the site. For facilities necessitating complex assessment, a time profile for the release should be provided. For example, in a severe accident at a nuclear power plant, initially noble gases would be released followed then by volatile radioactive material and subsequently by other fission products. This time profile to the release may be taken into account by separating the source term into different phases.

5.74. As an indication, the source term should include the composition and amounts of radionuclides, the physical (e.g. gas or aerosol) and chemical form, the release point, the height (for an aerial release) or depth (for an aquatic release), and the timing and the duration of the release. The flow speed and the thermal energy associated with the release may be also necessary to assess the effective height the radioactive plume could reach.

5.75. For the initial assessment of the impact of unexpected releases within the decision process for facilities and activities (e.g. in an EIA for a nuclear power plant), a reduced number of generic accident source terms may be used, as well as a reduced list of the main radionuclides (e.g. iodine-131, caesium-137, radioactive noble gases), considering their radiological significance. This source term could be based on published data or on experience from safety assessments of similar facilities [50, 51]. Later in the authorization process, the complete set of relevant accident source terms could be more accurately characterized by mean of safety analysis techniques, including probabilistic safety analysis when required.

Dispersion and environmental transfer

5.76. For simple assessments, conservative meteorological and hydrological assumptions may be made. For example, a uniform wind direction for atmospheric dispersion and low environmental dispersion or dilution conditions at the time of the postulated accident may be assumed. Such assumptions give conservative results and avoid the need to obtain site specific data. If, with these conservative data, the results are above the selected reference criteria, more representative values for the applicable meteorological and hydrological parameters at the location should be considered. This also applies for more complex

assessments. This is discussed in more detail above in this Section in the considerations of the dispersion and environmental transfer for normal operations.

5.77. Meteorological and hydrological data collected over a year should be used to specify characteristic accident dispersion conditions. If the routine monitoring data collected or used for the assessment of normal operation are not sufficiently comprehensive for accident analysis (for instance, if data on the long-range transport of radioactive material parameters in the atmosphere or in aquatic media are missing) data should be obtained from relevant records. Data could also be derived from the analysis of numerical atmospheric or aquatic models.

5.78. For the analysis of potential exposures in a complex REIA, different times of occurrence for an accident, together with the associated probabilities, could be selected by means of adequate statistical sampling techniques (such as cyclic or stratified sampling). Alternatively, an assessment could be performed by using the full set of representative hourly meteorological data and carrying out a subsequent statistical analysis (in all cases, the selected dispersion conditions have to be associated with a frequency of occurrence or a probability). For simpler assessments, a single time or a small set of times for the occurrence of the accident should be selected, and it should be ensured that the meteorological data for that time are either conservative or characteristic for the site under consideration.

5.79. Applicable dispersion models for short-term releases should be used to estimate the dispersion and distribution in the environment of radionuclides at particular activity concentrations [8].

5.80. The season of the year at the time of occurrence of a release can have a significant influence on the likely concentrations of radionuclides in environmental media. It should be possible to take account of this in the models for the transfer of radionuclides through the environment. For example, the period of growth of a plant, the time of harvest, and water levels and snow levels could have significant influences on the dose estimations.

5.81. The types and amounts and the physical and chemical characteristics of radionuclides released during an accident may differ considerably from those for discharges in normal operation. Models for potential releases in accidents should be able to predict non-equilibrium conditions. In addition, there can also be significant short-term variations in conditions and, in view of the potential for a large fraction of the inventory to be released; it should also be possible to model transfer and dispersion of radionuclides in the environment for far distances.

5.82. As is the case for discharges in normal operation, for REIA conducted at an early stage of a decision or authorization process the transfer to the environment during accidental releases can be done by using simple cautious models and meteorological and hydrological data generic to the region (from published data or from records from the closest meteorological and hydrological stations). Subsequently, data from measurements conducted on the site or very close to the plant location or data from numerical meteorological and hydrological models would normally be available, as the procurement of such data is normally required during the site evaluation and construction stages. Site specific data should be analysed in order to characterize the environmental dispersion conditions properly for the selected location.

Exposure pathways to members of the public

5.83. The exposure pathways that are relevant for the major contributions to the dose due to accidental releases may be very different from the relevant exposure pathways for normal operation. For example, consumption of fresh milk or vegetables immediately following a severe accident at a nuclear power plant could be an important pathway for exposures due to short lived iodine radionuclides. Care should therefore be taken in the adequate identification of the exposure pathways and in their modelling.

5.84. An indicative list of exposure pathways relevant for potential exposure scenarios for both external exposures and intakes of radionuclides is given below:

(a) External irradiation due to deposition on skin;
(b) External irradiation from the source;
(c) External irradiation from the plume;
(d) Inhalation from the plume;
(e) Inhalation of resuspended material;
(f) External irradiation due to deposition on the ground or other surfaces;
(g) Intakes of radionuclides due to the inadvertent ingestion of radioactive material deposited on ground or other surfaces;
(h) Intakes of radionuclides due to the consumption of fresh and processed food and water.

5.85. In an initial assessment, for example for REIA for a decision process or at the early stages of a licensing process, the exposure pathways that are known typically to dominate accident scenarios can be selected (i.e. external irradiation from the plume and exposure due to deposition on surfaces, deposition on skin, inhalation, milk consumption, etc.) and the data on habits can be conservatively estimated using national or regional statistics. Subsequently, information for the more relevant exposure pathways for potential events for the selected site that are chosen on the basis of site surveys should be used.

Identification of representative person (for potential exposures)

5.86. For assessment of the possible radiological impacts of potential exposures, the persons likely to be most exposed in accident conditions should be identified as a representative person [55]. It should be taken into account that the representative persons for potential exposure scenarios may be different from those identified for normal operation.

5.87. Other representative persons may be identified depending on the characteristics of the accident or event and the time of year of the potential release, in accordance, for instance, with the prevailing meteorological or hydrological conditions.

5.88. For simple assessments or in the initial phase of complex assessments, the representative person for potential exposures could be a hypothetical person or a group of persons in a location (e.g. very close to the site) where a person is likely to receive the highest exposures in potential scenarios. Later, for complex assessments, the representative persons should be identified, in agreement with the regulatory body, by using site specific information where available. Care should be taken when selecting the representative persons, since the potential exposures can be influenced by the possible implementation of countermeasures. The assumption as to whether or not countermeasures are effectively applied is an option for consideration in REIAs on the basis of national practice and regulations. Nevertheless, these assumptions should be clearly indicated and considered when comparing with criteria for use in emergency preparedness and response [52].

5.89. In some Member States specific individual representative persons or groups of persons are selected while in others the distribution of doses or risks among larger affected population is taken into account.

Assessment of dose to representative person

5.90. In REIA for potential exposures, mean absorbed doses to the organ or tissue, weighted by an appropriate relative biological effectiveness (RBE) for the biological end point of concern (for doses in the range for deterministic effects) and the effective dose (resulting from the sum of the committed effective dose from internal exposure pathways and the effective dose from external exposure, for doses in the range of probabilistic effects) are generally calculated. If the probabilities determined in the specification of the source term and in the meteorological distribution are analysed, the dose can be converted into an indication of the risk of health effects by means of risk coefficients provided, for example, by ICRP [30] (see Annex II for more details). This conversion should be applied on the basis of national practices and regulations.

5.91. Different age groups should be given due consideration in assessing the radiological impacts of potential exposures owing to the differences in the exposure conditions and in the associated radiation effects. The consideration of age groups should be carefully examined during REIA. Experience has shown that infants are more exposed via some pathways, such as irradiation of the thyroid gland due to the incorporation of radioiodines, which could potentially be released in a nuclear reactor accident.

5.92. The relevant time periods over which exposures could occur and the relevant exposure pathways should be defined. For example, doses due to inhalation in the first 24 hours (mainly due to passage of the plume) or doses due to the ingestion of green vegetables over a three month period could be used as indicators of the main potential radiological impacts. In other cases, doses over longer periods could be estimated; for instance, from the time of an accident to one year afterwards. When comparing these with reference criteria, the time periods and exposure pathways under consideration should be indicated in the results.

5.93. The decision whether or not to include in REIA assumptions of countermeasures that might imply the reduction of the resulting dose to the selected representative persons (for example sheltering during the passage of the plume, thyroid prophylaxis with stable iodine or evacuation) is the responsibility of the regulatory body. The inclusion of countermeasures and the implications for the reduction of the estimated doses or indicators of risk have to be stated clearly in the reports and discussed when presenting the results and comparing them with criteria provided in GSR Part 7 [54].

Comparison of dose/risk with criteria

5.94. The BSS require that the likelihood and magnitude of potential exposures be considered and that restrictions (e.g. risk constraints) be established by the regulatory body. For potential exposures, the endpoints of the assessment may be expressed in terms of a dose or a measure of the risk of health effects and consequently, a dose or risk criterion should be established. Guidance on reference criteria for consideration of potential exposures is provided in Appendix I and discussed in Annex II. Another option may be to express the criteria in terms of a level of consequences that would be unacceptable. For instance, a criterion could be that large evacuations of populations or long term restrictions on food

consumption or on the use of land as a result of the possible accident scenarios specified for the facility or activity would not be acceptable. In general, this level of consequences can be derived from an estimation of a dose or a related quantity and comparison to criteria set to establish the need of countermeasures. The criteria established by the regulatory body for use in preparedness and response to accidents should be in line with the requirements in [54] and could be used to define the level of acceptable consequences during REIA. Examples of use of those criteria are available in [52].

5.95. Different criteria may be set for facilities and activities with varying levels of inventory and technological complexity. The criteria should also reflect the level of conservatism required for the analysis (e.g. a regulatory body may specify one set of acceptance criteria for the nuclear fuel cycle and another set of acceptance criteria for hospitals or small laboratories).

5.96. Various international bodies and regulatory bodies have considered reference criteria for potential exposures due to accidental radioactive releases. Appendix I presents examples of criteria in terms of doses, risk and unacceptable levels of consequences as specified by the ICRP [30] and by the International Nuclear Safety Group (INSAG) [31]. These criteria could be used as a reference on the basis of which regulatory bodies could establish their own safety goals for potential exposures, particularly for those facilities necessitating complex assessments[23].

5.97. When considering transboundary impacts the criteria used for the consideration of potential exposures in REIA should be the same for all States being assessed.

CONSIDERATIONS ON THE IMPACTS OF POTENTIAL EXPOSURES ON THE ENVIRONMENT

5.98. The current section discusses briefly some possible approaches to consider or use potential exposures to flora and fauna during REIA of prospective nature at the early phase of a decision process, for example, when alternative sites are under consideration.

5.99. A way to use the results of the assessment of potential exposures to flora and fauna during planning phases may be for the consideration of different siting options, for a specific source (such as placing an outlet into a river, or an estuary, or the sea) with regard to the potential environmental impact of unexpected releases of radionuclides into these different media [28]. Those results may be also used to identify, at the time or planning, design or construction of the installations, the practical mitigating measures that may be available (for example, simple barriers or deviations to avoid large liquid accidental releases to the more sensitive ecological systems). The assessment of the dose rates to representative organism may serve as a point of reference in such considerations, and be used as a mechanism to compare impacts [28].

5.100. In an integrated optimization assessment, at the same time that the protection of humans is optimized considering social and economic features, one objective might be to include considerations on the radiological impact to flora and fauna. A level of ambition for protection of the environment could be established by the national regulator or the competent

[23] Discussions on the specification and use of criteria for potential exposures as well as examples of approaches adopted in some Member States are included in Annex II.

governmental agency considering the DCRL band as an appropriate point of reference for optimization, taking into account the radiological and non-radiological consequences. The consideration could be given to reduce exposure, assuming that the costs and benefits are such that further efforts are warranted as part of the overall optimization.

VARIABILITY AND UNCERTAINTY IN REIA

5.101. Uncertainty reflects the state of knowledge about the system being investigated and relates to how accurately the doses can be estimated: for example, how well all of the parameters values in the calculation of doses are known. The variability refers to the genuine differences that occur both in the transfer in the different environments and, for the case of humans, between individuals within a group: for example, differences in how much of a particular food they eat or where they spend their time. When defining the methodology, including the acceptance criteria, the regulatory body or the proposers of the facility or activity, as appropriate, should consider the aspects related to variability and uncertainty (some aspects are discussed in the following paragraphs).

5.102. Sensitivity analyses techniques can be useful for identifying which parameters are important in determining the overall impacts and should be applied when possible.

5.103. In general REIA provides a single result for each endpoint — for example, the dose to the representative person. This type of analysis is called deterministic analysis and should be based on best estimates or conservative assumptions of the parameter values used. The variability of the results due to the distribution of the parameters which are used to estimate doses could be assessed using different techniques, like Monte Carlo calculations, and incorporated to the results appropriately. It is important that this variability in the results is addressed properly to facilitate the decisions by the governmental agencies and the regulators and the communication with other stakeholders, like the general public.

5.104. REIA, generally, tends to be conservative by nature, in order to avoid underestimating the impact to the public and the environment. If the doses calculated are small fractions of the acceptance criteria or reference level, simple methodologies could be considered sufficient. When the doses estimated are closer to the acceptance criteria, the regulatory body could decide that more complex methodologies, including the use of site specific data, are necessary to increase the realism in the assessment.

5.105. For humans, any uncertainties in the assessment should be adequately small to ensure that the actual doses to members of the public do not exceed the dose limits, and are optimized below dose constraints set by the national regulatory body. ICRP, in its Publication 101 [33], has suggested that statistical methods and models could be used, noting that the parameter values used in environmental models and other data used in the calculation of doses (habit data and dose coefficients) are usually represented by distributions. ICRP 101 [33] provides examples on how these distributions can be chosen, as well as information on how to carry out calculations using these distributions and also on how to interpret the results. In order to consider the uncertainties in a REIA, in general, for environmental parameters single recommended values in bibliography [9, 10, 43] or average measured values, when available, should be used. For assessments using single values of habit data, high percentiles in the habit data distribution should be used (for instance, the 95% percentile in the food consumption rates); for assessments considering the distribution of the habit data, the resulting dose in the 95% percentile should be used to be compared with the established criteria.

5.106. For reducing the impact of uncertainties in the assessments of doses to members of the public, the establishment of environmental monitoring programmes, once the installation is operating, would provide confidence that the predicted doses are reasonable and real doses are not underestimated.

5.107. If insufficient information or data is available then a conservative estimate should be used but sensitivity studies should be carried out to determine how important an individual assumption is in determining the overall risk. It should be avoided to compound many conservative assumptions on top of each other and arrive at a result for the impact that is grossly pessimistic.

5.108. For flora and fauna, the more important source of uncertainties — apart from that due to environmental dispersion and transfer uncertainties similarly to those in the case of modelling for humans — could be the lack of knowledge and data on effects due to increments of radiation exposure levels, in most of the cases comparable to the variations of natural levels of background radiation, and the complex relations an interactions at the level of populations of species and ecosystems. However, this source of uncertainty is of minor importance, if the increments of exposures are within the variations of the natural background doses. In most of the exposure situations related to normal operation of facilities or activities, the resulting dose rates would be significantly low when compared to dose rate levels where radiological effects on individuals are expected. In addition, the number of individuals in the populations most highly exposed are fractions which, when compared to the total size of the populations, permits to conclude that the impact at the level of the entire sub-populations is insignificant.

5.109. A national regulatory body could identify some exposure conditions to some flora and fauna needing especial considerations different from those more of a generic character as presented in this Safety Guide. The existence of, for example, endangered species or very sensitive ecological niches could need a less generic assessment. Nevertheless, the methods described in this Safety Guide could be used as a screening tool for those particular circumstances.

5.110. The problem of dealing with variability and uncertainty in the assessment of potential exposures is even more difficult, as there are many more sources of uncertainty; these include, for example:

(a) Selection of accident scenarios. The scenarios selected may not be representative of what might actually happen and the list might not be complete, e.g. some types of scenario or failure mode may have been overlooked.
(b) The probability or frequency of the scenarios. Conservative analysis seeks to avoid the issue by assuming certain bounding representative initiating events and system failures occur. If the assessment is based on best estimates, for example if probabilistic safety analysis techniques are used to estimate accident frequencies, these frequencies are determined by combining many other frequencies and failure probabilities all with their own uncertainties and so are usually subject to quite large uncertainties.
(c) Unlike normal exposures which usually occur more or less continuously and can be averaged over a year smoothing out any inherent variability, potential releases will usually by short and the impact will be dependent on conditions at the time i.e. the meteorological conditions, the location of members of the public, etc.
(d) Unlike for normal exposures where environmental monitoring can retrospectively confirm the validity of the assessment, this is not possible for potential exposures.

5.111. Sensitivity studies could be carried out to determine how sensitive the overall result is to any source of uncertainty. The overall result could be sensitive to one or several parameters and assumptions on the underlying exposure scenario. Further research, modelling, or experimental data collection may need to be carried out, if the reduction of the level of uncertainty is deemed to be necessary.

APPENDIX I. REFERENCE CRITERIA FOR CONSIDERATION OF POTENTIAL EXPOSURES

I.1. Risks of health effects to members of the public arise both from exposure resulting from normal operation of facilities and activities and from possible accidental releases of radioactivity due to potential accidental scenarios. National authorities in the country should be responsible for setting reference criteria for potential exposure since the appropriate value may vary according to the prevailing legal, economic and social conditions [45]. International schemes which could be used to define national approaches for reference criteria for potential exposures are summarized and discussed below.

INSAG

I.2. The International Nuclear Safety Advisory Group (INSAG) considered safety goals for potential exposure (INSAG 9) [31] making the following statements for individual risk to a member of the public:

> "It seems appropriate that for members of the public a risk for potential exposure, expressed as the annual probability of death attributable to a single installation, should not exceed 10^{-5}."
>
> "…it seems reasonable to expect that accidents that require simple, local countermeasures" [dose to most exposed member of the public of 10–100 mSv] "should have an annual probability of not more than about 10^{-4}."
>
> "An annual probability of such an accident" [more severe accidents with a dose to most exposed member of the public of 1 Sv] "of 10^{-5} is likely to be required because of the societal consequences."

I.3. The annual probabilities for the last two criteria — accidents leading to dose of 10-100 mSv and 1 Sv are lower than would be implied by the first criterion of the annual probability of death of 10^{-5} given the currently accepted value of 0.05 probability of death per Sv for members of the general population; this accounts for the fact that for accidents giving rise to larger doses, there will be consequences additional to those of the radiation exposure such as implementation of counter-measures.

I.4. INSAG 9 also considers societal risk saying: In judging what steps are reasonable for reducing risks, decisions based on individual risk alone are insufficient. The number of individuals at risk and the economic and social implications of the accident are also relevant. These issues are often grouped together and termed societal risk.

I.5. INSAG 9 goes on to say that application of societal risk criteria is problematic. It suffers from the same problems as does individual risk for large releases as discussed above — the total impact includes other economic impacts as well as the radiation exposure.

I.6. Risk targets from INSAG 3 [53] are quoted: a severe core damage frequency of less than 10^{-4} events per year for existing nuclear power plants which with the application of all safety principles should be not more than 10^{-5} events per year for new nuclear power plants. Severe accident management and mitigation measures should reduce by a factor of at least ten the probability of major external radioactive releases requiring off-site response in the short term. It states that this would correspond to an individual risk of death for a member of the public of much less than 10^{-5} per plant operating year for existing and 10^{-6} for new plant.

TABLE 4. RANGE OF PROBABILITIES IN A YEAR FROM WHICH CONSTRAINT MAY BE SELECTED (FROM ICRP 64) [30]

Impact	**Probability Range**
Sequences of events leading to doses treated as part of normal exposures	10^{-1} to 10^{-2}
Sequences of events leading to stochastic effects only but above dose limits	10^{-2} to 10^{-5}
Sequences of events leading to doses where some radiation effects are deterministic	10^{-5} to 10^{-6}
Sequences of events leading to doses where death is likely to result	$< 10^{-6}$

ICRP

I.7. The International Commission on Radiological Protection (ICRP) [30] has recommended that for the treatment of potential exposure, the risk limits should be of the same order of magnitude as the health risk implied by the dose limits for normal exposures [2]. It adds:

> "One procedure for applying source-related constraints is to express the probability of an event sequence as a function of the dose that will be delivered should the sequence actually occur. Such a constraint would express the maximum probability that can be permitted from sequences exceeding a given magnitude of dose."

I.8. Such a scheme is proposed and is reproduced in Table 4. For complex systems, similar sequences should be grouped adding their probabilities and taking the worst consequence from any individual sequence to represent the group as a whole. ICRP states that the values in Table 4 are intended to illustrate the types of constraint that might be imposed based on experience taking into account the benefits derived from the particular practice. It adds that the values might also be imposed as tentative constraints in the absence of operating experience, subject to revision as experience is gained and in such cases the constraints may be regarded as upper bounds. ICRP emphasizes that these constraints refer to potential exposure of an individual and other constraints may apply for limiting probabilities of other consequences such as socially disruptive effects.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards, Interim Edition, General Safety Requirements Part 3, No. GSR Part 3 (Interim), IAEA, Vienna (2011).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Fundamental Safety Principles, IAEA Safety Standards Series No. SF 1, IAEA, Vienna (2006).

[3] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, The 2007 Recommendations of the International Commission on Radiological Protection', ICRP Publication 103, Elsevier (2007).

[4] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, The 1990 Recommendations of the International Commission on Radiological Protection, ICRP Publication 60, Pergamon Press (1990).

[5] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Environmental Protection: the Concept and Use of Reference Animals and Plants, ICRP Publication 108, Elsevier (2008).

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Radiation Protection of the Public and the Environment, IAEA, Vienna (Draft DS 432).

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, Regulatory control of the releases of radioactive material from facilities and activities (Revision of WS-G-2.3), IAEA, Vienna (Draft DS 442).

[8] INTERNATIONAL ATOMIC ENERGY AGENCY, Generic Models for Use in Assessing the Impact of Discharges of Radioactive Substances to the Environment, IAEA Safety Report Series No. 19, IAEA, Vienna (2001).

[9] INTERNATIONAL ATOMIC ENERGY AGENCY, Handbook of parameter values for the prediction of radionuclide transfer in terrestrial and freshwater environments, Technical Reports Series No. 472, IAEA, Vienna (2010).

[10] INTERNATIONAL ATOMIC ENERGY AGENCY, Handbook of Parameter Values for the Prediction of Radionuclide Transfer to Wildlife, Technical Reports Series, IAEA, Vienna (in press).

[11] INTERNATIONAL ATOMIC ENERGY AGENCY, Environmental and Source Monitoring for Purposes of Radiation Protection, IAEA Safety Guide No. RS-G-1.8, IAEA, Vienna (2005).

[12] INTERNATIONAL ATOMIC ENERGY AGENCY, Assessment of Occupational Exposure Due to External Sources of Radiation, Safety Guide, IAEA Safety Standards Series No. RS-G-1.3, IAEA, Vienna (1999).

[13] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Assessment and Verification for Nuclear Power Plants, IAEA Safety Standards Series No. NS-G-1.2, IAEA, Vienna (2001).

[14] INTERNATIONAL ATOMIC ENERGY AGENCY, Establishing the Safety Infrastructure for a Nuclear Power Programme Specific Safety Guide, IAEA Safety Standards Series No. SSG-16, IAEA, Vienna (2012).

[15] UNITED NATIONS ECONOMIC COMMISSION FOR EUROPE, Convention on Environmental Impact Assessment in a Transboundary Context, the 'Espoo (EIA) Convention', UNECE, Espoo, Finland (1991).

[16] UNITED NATIONS, UN Convention on the Law of the Sea, 10 December 1982, UNCLOS (1982).

[17] UNITED NATIONS ECONOMIC COMMISSION FOR EUROPE, Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters, 25 June 1998, UNECE, Aarhus, Denmark (1998).
[18] EUROPEAN COMMISSION, European Council Directive on the assessment of the effects of certain public and private projects on the environment (1985, 1997, 2003).
[19] United States Government, The National Environmental Policy Act, NEPA (1969).
[20] Law of the People's Republic of China on the Environmental Impact Assessment (2003).
[21] ARGENTINA Law 26.765 "General Law of the Environment" link: http://www.corebe.org.ar/NORMATIVA/ley_general_del_ambiente.htm (in Spanish).
[22] AUSTRALIAN AND NEW ZEALAND ENVIRONMENT AND CONSERVATION COUNCIL, Guidelines and Criteria for Determining the Need for and Level of Environmental Impact Assessment, prepared by The ANZECC Working Group on National Environmental Impact Assessment, ANZECC, Canberra (1996).
[23] INTERNATIONAL ATOMIC ENERGY AGENCY, Format and Content of the Safety Analysis Report for Nuclear Power Plants, IAEA Safety Standards Series No. GS-G-4.1, IAEA, Vienna (2004).
[24] INTERNATIONAL ATOMIC ENERGY AGENCY, Licensing Process for Nuclear Installations, IAEA Safety Standards Series SSG 12, IAEA, Vienna (2010).
[25] INTERNATIONAL ATOMIC ENERGY AGENCY, Governmental, Legal and Regulatory Framework for Safety, General Safety Requirements Part 1, No. GSR Part 1, IAEA, Vienna (2010).
[26] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Assessment for Facilities and Activities, General Safety Requirements Part 4, No. GSR Part 4, IAEA, Vienna (2009).
[27] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, A Framework for Assessing the Impact of Ionising Radiation on Non-Human Species, ICRP Publication 91, Elsevier (2003).
[28] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Protection of the Environment under Different Exposure Situations, ICRP Publication 124, Elsevier (in press).
[29] INTERNATIONAL ATOMIC ENERGY AGENCY, Terminology used in Nuclear Safety and Radiation Protection, IAEA Safety Glossary, IAEA, Vienna (2007).
[30] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Protection from Potential Exposure – A Conceptual Framework, ICRP Publication 64, Pergamon (1992).
[31] INTERNATIONAL ATOMIC ENERGY AGENCY, Potential Exposure in Nuclear Safety, A Report by the International Nuclear Safety Advisory Group, INSAG Series No. 9 (INSAG-9), IAEA, Vienna (1995).
[32] INTERNATIONAL ATOMIC ENERGY AGENCY, Regulatory Control of Radioactive Discharges to the Environment, IAEA Safety Standard Series No. WS-G-2.3, IAEA, Vienna (2000).

[33] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Assessing Dose of the Representative Person for the Purpose of Radiation Protection of the Public and The Optimisation of Radiological Protection: Broadening the Process, ICRP Publication 101a/b (2006).
[34] EUROPEAN ATOMIC ENERGY COMMUNITY, Treaty establishing the European Atomic Energy Community, EURATOM, (1957).
[35] UNITED NATIONS SCIENTIFIC COMMITTEE ON THE EFFECTS OF ATOMIC RADIATION, Sources and Effects of ionizing Radiation, Report to the General Assembly, with Scientific Annexes: Sources. UN, New York (1993).
[36] UNITED NATIONS SCIENTIFIC COMMITTEE ON THE EFFECTS OF ATOMIC RADIATION, Sources and Effects of ionizing Radiation. Report to the General Assembly, with Scientific Annexes, Vol 1: Sources, UN, New York (2000).
[37] INTERNATIONAL ATOMIC ENERGY AGENCY, Screening Assessment of Public Exposure, Assessing Public Exposure and Environmental Impacts due to Radioactive Discharges from Facilities and Activities, IAEA, Vienna (in press).
[38] INTERNATIONAL ATOMIC ENERGY AGENCY, Sediment Distribution Coefficients and Concentration Factors for Biota in the Marine Environment, Technical Reports Series No. 422, IAEA, Vienna (2004).
[39] INTERNATIONAL ATOMIC ENERGY AGENCY, WORLD METEOROLOGICAL ORGANIZATION, Meteorological and Hydrological Hazards in Site Evaluation for Nuclear Installations, IAEA Safety Standards Series No. SSG-18, IAEA, Vienna (2011).
[40] INTERNATIONAL ATOMIC ENERGY AGENCY, Site Evaluation for Nuclear Installations, IAEA Safety Standards Series No. NS-R-3, IAEA, Vienna (2003).
[41] INTERNATIONAL ATOMIC ENERGY AGENCY, Dispersion of Radioactive Material in Air and Water and Consideration of Population Distribution in Site Evaluation for Nuclear Power Plants, IAEA Safety Standards Series No. NS-G-3.2, IAEA, Vienna (2002).
[42] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Age-dependent Doses to the Members of the Public from Intake of Radionuclides – Part 5, Compilation of Ingestion and Inhalation Coefficients, ICRP Publication 72, Pergamon (1995).
[43] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Environmental Protection: Transfer parameters for Reference Animals and Plants, ICRP Publication 114, 1st Edition, 39 6, Elsevier (2011).
[44] PROEHL, G., BROWN, J., GOMEZ-ROS, J-M., JONES, S., WOODHEAD, D., VIVES, J., TARANENKO, V., THØRRING, H., Dosimetric models and data for assessing radiation exposure to biota, Deliverable 3 to the project, "FASSET" Framework for the Assessment of Environmental Impact, Contract No. FIGE-CT-2000-00102, Swedish Radiation Protection Authority (2003).
[45] INTERNATIONAL ATOMIC ENERGY AGENCY, The Role of Probabilistic Safety Assessment and Probabilistic Safety Criteria in Nuclear Power Plant Safety, IAEA Safety Series No. 106, IAEA, Vienna (1992).
[46] INTERNATIONAL ATOMIC ENERGY AGENCY, **S**afety of Nuclear Power Plants Design, Specific Safety Requirements Series No. SSR-2/1, IAEA, Vienna (2012).
[47] INTERNATIONAL ATOMIC ENERGY AGENCY, Development and Application of Level 2 Probabilistic Safety Assessment for Nuclear Power Plants, Specific Safety Guide SSG-4, IAEA, Vienna (2010).

[48] INTERNATIONAL ATOMIC ENERGY AGENCY, Accident Analysis for Nuclear Power Plants, IAEA Safety Reports Series No. 23,IAEA, Vienna (2002).
[49] INTERNATIONAL ATOMIC ENERGY AGENCY, Derivation of the Source Term and Analysis of the Radiological Consequences of Research Reactor Accidents, IAEA Safety Reports Series No. 53, IAEA, Vienna (2008).
[50] INTERNATIONAL ATOMIC ENERGY AGENCY, Accident Analysis for Nuclear Power Plants, IAEA Safety Reports Series No. 23. IAEA, Vienna (2002).
[51] UNITED STATES NUCLEAR REGULATORY COMMISSION, Accident Source terms for Light-Water Nuclear Power Plants, NUREG-1465, US NRC (1995).
[52] INTERNATIONAL ATOMIC ENERGY AGENCY, Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency, General Safety Guide, IAEA Safety Standards Series No. GSG-2, IAEA, Vienna (2011).
[53] INTERNATIONAL ATOMIC ENERGY AGENCY, Basic Safety Principles for Nuclear Power Plants, A Report by the International Nuclear Safety Advisory Group, 75-INSAG-3 Rev. 1, IAEA, Vienna (1999).
[54] INTERNATIONAL ATOMIC ENERGY AGENCY, Preparedness and Response for a Nuclear or Radiological Emergency, General Safety Requirements Part 7, IAEA, Vienna (Draft DS 457).
[55] INTERNATIONAL ATOMIC ENERGY AGENCY, Actions to Protect the Public in an Emergency due to Severe Conditions at a Light Water Reactor, Emergency Preparedness and Response Series EPR-NPP PUBLIC PROTECTIVE ACTIONS, IAEA, Vienna (2013).
[56] INTERNATIONAL ATOMIC ENERGY AGENCY, Dangerous Quantities of Radioactive Material, Emergency Preparedness and Response Series EPR-D-VALUES, IAEA, Vienna (2006).

ANNEX I. CONSIDERATIONS ON ASSESSMENTS OF RADIOLOGICAL IMPACT TO FLORA AND FAUNA

I-1. ICRP and the IAEA have defined high level principles for protection of the environment. According to ICRP [I-1, I-2, I-3] the aims of environmental protection are to prevent or reduce the frequency of deleterious radiation effects on biota to a level where they would have a negligible impact on the maintenance of biological diversity, the conservation of species, or the health and status of natural habitats, communities, and ecosystems. IAEA [I-4] establishes a safety principle requiring the protection of ecosystems against radiation exposure that would have adverse consequences for populations of a species (as distinct from individual organisms).

I-2. Owing to the complexity in the interaction of different species and the lack of knowledge about the radiological effects on populations exposed to very low increments of the levels of radiation —comparable in many cases with the variations on the natural radiation background— the impact to ecosystems and to populations of species in those ecosystems cannot be currently explicitly modeled, especially for the levels of radiation expected during normal exposure situations. Nevertheless, conclusions on the radiological impacts on populations of species, which can be applied prospectively to control radioactive sources in planned exposures situations, could be extrapolated from the assessment of the exposures of a reduced number of individual organisms, used as a reference.

The reference approach for radiological protection of flora and fauna

I-3. A pragmatic approach to assess the effects of radiation on flora and fauna is to model the exposures of reference flora and fauna and consider the existing information on radiation effects. The explicit assessment of the radiological impact to flora and fauna is a relatively recent development in the area of radiological protection. The approach adopted by ICRP to assess the radiological impact on flora and fauna is consistent with the approach used for humans.

I-4. In the system of radiological protection for humans ICRP [I-2] defines a model called the reference person and the methods to calculate its doses that can be used in the assessment of the radiological impact to members of the public. In a similar manner for flora and fauna ICRP has defined in its Publication 108 [I-2] a small set of 'reference animals and plants' (RAPs), including models for their dosimetry. A RAP is defined [I-2, I-3] as *a hypothetical entity, with the assumed basic biological characteristics of a particular type of animal or plant, as described to the generality of the taxonomic level of family, with defined anatomical, physiological, and life history properties that can be used for the purposes of relating exposures to dose, and dose to effects, for that type of living organism.*

I-5. ICRP recommends that the dosimetric model of the reference person should be applied to the calculation of doses for a representative person and compared to a reference criterion. Recently ICRP has defined the concept of representative organism consistently with the concept of representative person. The representative organism represents the flora and fauna most highly exposed. ICRP Publication 124 [I-3] indicates that representative organism is "*a particular species or group of organisms selected during a site specific assessment, taking account of their assumed location with respect to the source. In many cases the actual representative organisms chosen for this purpose may be the same as, or very similar to, the RAPs but in some cases they may be very different*".

I-6. In the same way that for humans the representative person should represent average exposure conditions of a certain group of individuals, the representative organism for flora and fauna should be a group of a particular species located where the exposure conditions leads to the highest doses and the estimated dose should be a dose that can be considered characteristic for all that group.

I-7. For flora and fauna, the protection goal focuses on species in the ecosystems against radiation exposure that could have adverse consequences for populations of species[24] (as distinct from individual organisms) [I-2, I-4]. To assess the impact at the level of population, an adequate number of representative organisms in the ecosystem of interest should be selected from those animals and plants most highly exposed. For the purpose of comparison with criteria, radiation exposure that is typical for this group of individuals represented in terms of reference animals and plants should be estimated. ICRP Publication 108 [I-2] discusses the consideration of populations and ecosystems and gives some information on the population sizes used in determining the reference animals and plants and representative organism.

Area where most highly exposures to flora and fauna are observed

I-8. To define the most highly exposed group of flora and fauna for generic assessments of radiological impact, it is important to consider the typical spatial distribution of radionuclides in the environment under planned exposures situation. In general, activities and facilities in normal operation can be considered as point sources with steady-state or semi-steady-state releases and, in most cases, the highest activity concentrations in air, soil, water and biota, averaged along the year, are normally found within the first 5–10 km from the sources. The activity concentrations in the environment decreases significantly with the distance from such highest concentrations. This is illustrated in Figure I-1, for atmospheric and aquatic dispersion. Due to the annual distribution of wind directions and, in some cases, the directions of the water flows in rivers, lakes and oceans, the highest activity concentrations could be detected in any direction within a radius of up to 10 km.

I-9. Therefore, an area of approximately 100–400 km^2 located around the release point would ensure that highest environmental activity concentrations due to normal releases are found within that area. Consequently the flora and fauna within that area would normally receive the highest radiation exposures to radiation. The group of animals and plants living in that area around the release point, where the highest environmental activity concentrations are observed, can then be defined as the representative organism of flora and fauna.

[24] The understanding of the population of a species may vary depending on the type of ecological study. For purposes of the radiological protection of flora and fauna, this Safety Guide considers a population to be a group of individuals of a single species that is demographically distinct from other such groups. Adverse consequences at the level of population can be, for example, impact on the reproductivity, stability, structure and distribution.

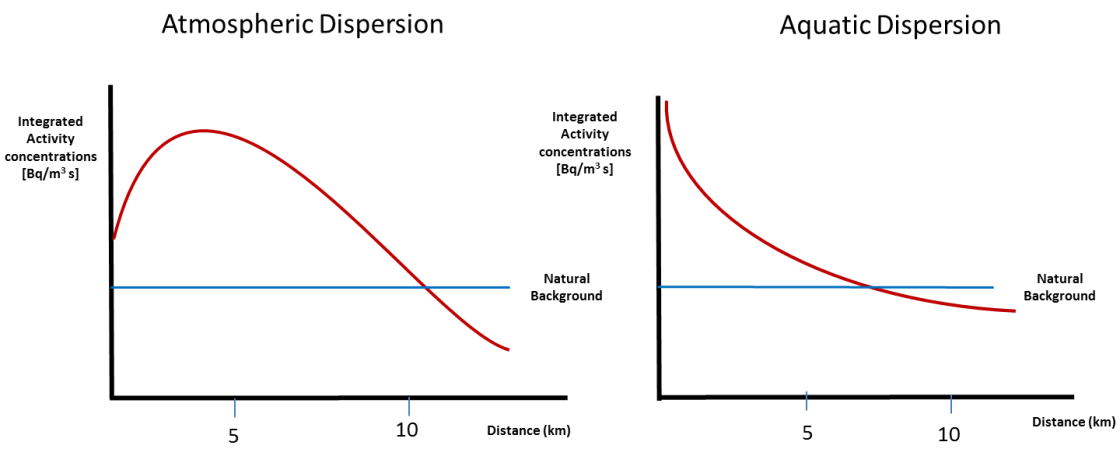

FIG. I-1. Typical patterns of environmental concentrations as a result of atmospheric and aquatic dispersion from a steady point source during normal releases from activities and facilities.

I-10. An area of 100-400 km^{2}around the source[25] is sufficiently large to ensure that mixing of the effluents with the environmental media occurs and that the number of individuals considered for the assessment is suitably large and representative of the fraction of the population highly exposed. The doses which are characteristic of the representative organisms can be obtained using the average activity concentrations in that area, in the different environmental media which are relevant for the internal and external exposures pathways for each reference animal and plant under consideration.

The reference criteria for flora and fauna

I-11. For evaluating level of radiological impact to flora and fauna, ICRP introduced 'derived consideration reference levels' (DCRLs) for the set of RAPs, as a point of reference to guide the level of effort expended on environmental protection [I-2]. In contrast to humans, for whom the radiological criteria are used to control stochastic effects for individuals, the DCRLs correspond to stochastic and deterministic effects observed for individual animals and plants (e.g. early mortality, some forms of morbidity, effects on reproduction, induction of chromosomal damage) which, depending on the number of individuals affected, could have an impact in the structure of the population of a species. Detectable effects in some single individuals of a population would not necessarily have consequences for the population as a whole [I-2]. The impact at the level of population is either not fully understood or is simply unknown and currently cannot be properly modeled, in particular at low doses [I-2]. The use of reference animals and plants in combination with DCRLs, which are based on information on effects with a low probability to individuals which may have an impact in the structures of populations, can be considered as a cautious approach, based on the current level of information and knowledge. A level of protection established by setting a reference criteria below or equal to the lower band of the DCRL's is to be considered an appropriate level of protection for flora and fauna.

[25] This area could be either a circle of about 5–10 km radius or a box of 10–20 km side, both centered at the release point.

I-12. Because DCRLs are not defined as limits, the estimated doses could be within the band or even above the bands and the radiological situation can still be considered acceptable taking into account different factors. ICRP 108 [I-2] identify the factors which should be considered when making decisions based on impacts to flora and fauna when the estimated doses are above the lower bound of the bands; these are: the size of the area where the dose rates are assessed to occur, the time period predicted for such dose rates, the need to comply with a specific legislation, the type of managerial interest, the presence of additional environmental stressors, whether or not the assessment is related to actual species or generalized to plants and animals types, the degree of precaution considered necessary.

The use of ICRP RAPs under different ecological conditions

I-13. ICRP RAPs where selected to be used as references considering the amount of quality data on radiobiology available, including data on probable radiation effects, that they are considered typical representative flora and fauna of particular ecosystems and have a wide geographical variation, as well as considering their potential use in a pragmatic manner [I-2]. RAPs are not intended to represent all the species in an ecosystem, but they can be used as indicators to set standards to control the exposures to all the species in the ecosystems. In the selection of this set consideration was taken on which species in the major ecosystems would be more affected due to the exposure of internal and external radiation owing to the presence of activity concentration in the environmental media.

I-14. While the ICRP RAPs are intended to provide information on the possible exposure conditions of a large number species and environmental situations, other reference animals and plants appropriate for significant different environmental conditions or to represent considerable different species present in a specific site can be derived, if deemed necessary and if information is available. This could be the case, for instance, for desert, artic or tropical climates, because some of the current ICRP RAPs are more representative of temperate climates (others are virtually ubiquitous). Another case needing consideration could be if the species in a particular site present considerable differences with the RAPs. Before attempting to complement or replace the RAPs defined by the ICRP consideration should be taken on where this is justified, based on scientific basis. The differences needing consideration are: in their biology (such as life span, or life cycle); in their dosimetry (because of size, shape, or location); and in their response to radiation at similar rates of (or total) dose [I-3]. To derive a new or complementary set of RAPs, a methodology similar to that presented in ICRP Publication 108 [I-2] should be used, e.g. for all such new designated reference animals and plants, information and modeling capabilities are needed to quantify relevant radionuclides transfer rates to whole organisms, the dosimetry and data on radiation doses effects.

REFERENCES

[I-1] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, The 2007 Recommendations of the International Commission on Radiological Protection', ICRP Publication 103, Elsevier (2007).

[I-2] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Environmental Protection: the Concept and Use of Reference Animals and Plants, ICRP Publication 108, Elsevier (2008).

[I-3] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Protection of the Environment under Different Exposure Situations, ICRP Publication 124, Elsevier (in press).

[I-4] INTERNATIONAL ATOMIC ENERGY AGENCY, Fundamental Safety Principles, IAEA Safety Standards Series No. SF 1, IAEA, Vienna (2006).

ANNEX II. CONSIDERATIONS ON ASSESSMENT OF POTENTIAL EXPOSURES AND NATIONAL EXAMPLES

Introduction

II-1. The Fundamental Safety Principles [II-1] states that "Safety is concerned with both radiation risks under normal circumstances and radiation risks as a consequence of incidents"[26]. Since it also establishes that 'safety' means the protection of people and the environment against radiation risks, there is a clear requirement to assess and control the impact from potential exposures on people and the environment.

II-2. The text in this Safety Guide refers to 'impact of potential exposures' which can be confusing owing that also the impact from an expected low dose (from normal operation) is potential, as detrimental health effects may never appear.

II-3. The radiation effective dose[27] combined with a risk factor can be interpreted as a measure of the risk that detrimental effects will materialize. ICRP [II-2] has suggested a risk coefficient for stochastic effects of 5×10^{-2} Sv^{-1}.

II-4. Generally, the radiological impact expected from operations and planned discharges from modern facilities or activities is very low. However, the unplanned or accidental releases of radionuclides to the environment, for some of these facilities and activities, could be an important radiological issue to be considered[28]. Nevertheless, the actual radiological risk (see definition in next Section) due to installations which have the potential to produce large releases of radionuclides to the environment under accidental conditions can be properly estimated and maintained below levels of concern. This is generally ensured from the design, by adding a multilevel (defence in depth) system of sequential, independent provisions for protection and safety that is commensurate with the likelihood and the magnitude of the potential exposures [II-3].

II-5. As mentioned in Appendix I, the ICRP [II-4, II-5] has recommended that for consideration of potential exposure, the risk constraints should be of the same order of magnitude as the health risk implied by normal operations. A typical risk due to normal operations of nuclear installations, based on generalizations about public exposures, can be estimated as an order of magnitude of 10^{-5} per year, assuming that annual doses to the public are in the order of 10^{-3} mSv .

II-6. The problem lies in the complexity to assess and quantify an impact of an accident or event that might happen, as opposed to one that is expected and could be assumed to happen (e.g. as is the case for planned discharges).

---

[26] Safety Fundamental Principles [II-1] states that: Incidents includes initiating events, accident precursors, near misses, accidents and unauthorized acts (including malicious and non-malicious acts), as well as with other possible direct consequences of a loss of control over a nuclear reactor core, nuclear chain reaction, radioactive source or any other source of radiation.

[27] IAEA Safety Glossary defines effective dose equivalent as a measure of dose designed to reflect the risk associated with the dose, calculated as the weighted sum of the dose equivalents in the different tissues of the body [II-6]. The definition of effective dose equivalent is superseded by effective dose.

[28] A large number of activities and facilities have potential of only minor or negligible radiological consequences even under accident scenarios owing to very limited inventories or the intrinsically safe characteristics of the sources.

II-7. Generally — and certainly in the case for facilities like NPPs and reprocessing plants — there will be a whole spectrum of possible potential exposure scenarios, ranging from those with little or no impact to those with a very high potential impact. Accident scenarios with a high radiological impact could be postulated by, for example, assuming that every single safety feature in the facility fails simultaneously. Accident scenarios could result also from the interaction of safety failures and the impact of severe external events like, for example, earthquakes. Since the likelihood of such an extreme scenarios is very low, it seems clear that the probability or frequency of occurrence must be taken into account for the postulated accidents with large radiological impacts.

II-8. This safety guide is focused in the approaches and methods to assess the radiological consequences for normal operation and potential exposures but does not go into the details of assessing the accident source terms and their associated likelihoods (e.g. it assumes that the source terms and their probabilities are provided to the analyst applying this Safety Guide). Nevertheless, it is clear that one important problem when assessing potential exposures is how to calculate or estimate these source terms and their likelihoods.

Definition of a measure of risk

II-9. A term that is often introduced to express a combination of an impact of an event or scenario and the likelihood of that impact is 'risk'. Various schemes have been developed to quantify its combination and thus, allow the risk or risks of various events to be directly compared. Confusion can arise between this term with a defined meaning and mathematical definition, and the everyday meaning of the word 'risk' which can be synonymous of hazard.

II-10. The BSS [II-3] defines 'risk' as "multi-attribute quantity expressing hazard, danger or chance of harmful or injurious consequences associated with actual or potential exposures". It relates to quantities such as the probability that specific deleterious consequences may arise and the magnitude and character of such consequences.

II-11. As explained in the main text of this Safety Guide, when using a probabilistic approach for assessing the impact of potential exposures, for each potential exposure scenario, a consequence (e.g. a dose to representative person) and the associated probability of that consequence has to be determined.

II-12. For radiation safety purposes it could be useful to define a single mathematical definition of a measure of individual health risk[29] [II-7]. Since the consequence of a radiation dose can be expressed as the increased probability of severe health effects (for example death from early cancer)[30], an indication of the risk can be evaluated by combining the probability of the scenario *i* occurring (p_i) and the probability of the health effects if it occurs (C_i).

[29] The definitions of 'risk' described in this Annex can only be interpreted as giving an indication of the risks, owing to the many uncertainties involved in a probabilistic safety analysis as it was described, in the estimation of the possible exposures and in the quantification of the associated radiological consequences.

[30] To be more precise, the probability of the health effect can be estimated using the dose response function, f(D), which changes with the level of dose . The risk of early health effects can also be calculated using hazard functions, taking into account the variation of risk with the rate at which dose is accumulated over a certain period (e.g. the first day or few days following the accident). The risk of late health effects can consider not only fatal but non-fatal cancers in different organs, leukaemia and hereditary effects. The details of these considerations are out of the scope of this Annex which should be considered as introductory to the topic.

$$R_i = p_i \times C_i \quad \text{(II-1)}$$

where R_i is the risk of health effect due to potential exposure scenario i.

II-13. If the events are mutually independent and the probabilities of the events are low, the risks of all the potential exposure scenarios could then be added to give the overall probability of health effect to the representative person:

$$R = \sum_i \ p_i \times C_i \quad \text{(II-2)}$$

II-14. As discussed in the previous paragraphs, the risk estimated within a REIA could apply to the representative person — but for large facilities such as NPPs which have the potential to affect many individuals and cause other impacts on society such as evacuation and land restriction, some measure of the societal risk could also need to be quantified and assessed against a criteria. The consideration of societal risk is not included in the present guidance.

II-15. Reference risk criteria which could be used in REIA are presented in Appendix I of this Safety Guide based on [II-8] and [II-4].

Practicable applications to consider potential exposures

II-16. As discussed in the main document in Section 5, this Safety Guide presents the generalities of three possible ways to assess potential exposures:

(a) by selecting a conservative accident source term (named here as a conservative approach); or
(b) by estimating a characteristic[31] or a set of characteristic potential accident source terms (named here as a charateristic approach); or
(c) by identifying accident or event sequences from a broad range of initiating events by means of a methodological approach and estimating a set of potential source terms with their probabilities (named here as probablitisic approach).

In all three cases, the assessment of the potential exposures include the estimation of the associated potential radiological consequences for the above mentioned source terms combined, where necessary, with the relevant probabilities.

II-17. Because accidents and radiological consequences have both a probabilistic characteristic, the problem to solve is always of a probabilistic nature, while the analysis can be done with or without considering the involved probabilities. In the first two cases — (a) and (b) — a single accident or a reduced set of accidents predefined accidents are used to estimate the potential consequences, generally in the form of a dose. In the last case — (c) — a set of accidents are selected with probabilistic techniques based in the analysis of the response of the safety systems and the consequences are estimated in the form of a measure of risk.

[31] Characteristic accidents are accidents that, as a result of the safety assessment, can be considered to be a comprehensive representation of the safety characteristics of the facility. The accidents identified can be divided into different categories in accordance with their annual frequency or likelihood of occurrence and their consequences. Characteristic accidents do not necessarily include the worst case scenario.

II-18. In the conservative approach, the source term is defined without considering or estimating the probability of occurrence and the resulting consequences cannot be considered as an indication of the risk. However, when the radiological consequences are small (e.g. a few mSv), the analysis allows to conclude that the potential exposures are acceptable irrespectively of the probability of occurrence. This type of analysis is typically applicable to activities and facilities with small total inventories (e.g. hospitals and laboratories) and associated with the assumption that the dispersion and transfer to the environment are also conservative.

II-19. In the characteristic approach a dose is estimated for each source term, which is selected considering predefined accidents with a certain annual frequencies, resulting from safety analysis, and then it is compared to a dose criterion. Usually, different dose reference values are considered for the different annual frequencies (e.g. for accidents with higher frequencies the doses must be lower than for the accidents with very low frequency). The assumptions in the environmental and transfer conditions are also selected as characteristic for the site under consideration. Although the endpoint of this assessment is also a dose, owing to the fact that some frequencies are involved in the selection of the characteristic accidents, there is an implicit notion of risk.

II-20. In the probabilistic approach, a larger set of source terms and their associated annual frequencies are combined with the environmental transfer probabilistic properties[32] for the site, which permit to obtain a distribution of doses with the associated probabilities. The result is normally expressed in terms of a measure of the risk of health effects and the acceptance criteria are also expressed as a reference risk. The following section discusses the general features of the probabilistic approach.

Basic characteristics of the probabilistic approach

II-21. In this approach, frequencies of initiating events are estimated and the possible fault sequences (or a representative sub-set) that encompass the responses of plant and safety systems, including human operators, are determined. The overall probability or frequency of the fault sequence or scenario is calculated by combining the frequency of the initiating events with probabilities of each failure of event in the sequence. The use of probabilities and frequencies implies a definition of a period of time which can be selected arbitrary in order to perform the analysis. A period of one year is usually selected.

II-22. Then, the source term for each sequence is calculated. In some cases a bounding source term may be used for a set of fault sequences to reduce the calculation required.

II-23. The dose to the most exposed individual or individuals are then calculated by using a set of meteorological conditions or other environmental transfer conditions along with the probabilities of these conditions applying along with factors that affect the dose and their probabilities. For a given source term and target, one would need to include: for example, the probability that the wind was blowing from the source to the target, the probability of other meteorological conditions such as stability, wind speed, rainfall etc., the probability that the person is outdoors or indoors, and so on.

II-24. The doses obtained are combined with the probabilities of those doses being incurred to give an indication of risk which is then compared with acceptability criteria.

[32] The environmental transfer probabilistic properties are determined, for example, by the wind rose, the atmospheric dispersion stability classes observed, the rain patterns, etc.

EXAMPLES OF CONSIDERATION OF POTENTIAL EXPOSURES FROM DIFFERENT COUNTRIES

NOTE: Member States are invited to provide additional examples.

European utility requirements (LWR NPPs only)

II-25. In 1991 the major European electricity producers formed an organization to develop the European Utility Requirement (EUR) document [II-9] to set out a common set of Utility Requirements for the next generation of LWR nuclear power plants. Prior to these requirements, the development, design and licensing of existing LWR plants had been performed on a national basis with little interaction between countries.

II-26. The EUR document sets common safety targets which are consistent with the best European and international objectives. It states that these targets are values that are more restrictive than regulatory limits but are judged to be at a level that can be reasonably achieved by modern well-designed plants. Targets are set for normal operation, incident conditions, and accident conditions. For the preliminary design assessment, EUR has proposed criteria in terms of radionuclide releases rather than doses to members of the public. The targets are generally defined as linear combinations of the releases in each of the reference isotopic groups and depend on the category of the accident as determined by the estimated frequency of the initiating event. The detailed methodology can be found in Volume 2 of the EUR Document [II-9].

UK Nuclear Regulator

II-27. The UK nuclear safety regulator has issued Safety Assessment Principles which provides guidance to set numerical targets for potential exposures [I-10, I-11]. Table II-1 below summarizes the guidance on numerical targets applicable for off-site releases in the UK. These figures are termed Basic Safety Levels which represent a level that it is considered a new facility should meet; Basic Safety Objectives are set more stringent, for instance at lower levels (generally a factor of 100 lower) and mark the start of what is considered broadly acceptable. There are also targets for workers on-site.

TABLE II-1. UK NUMERICAL TARGETS FOR POTENTIAL EXPOSURES OFF-SITE

Target	Applicability	Numerical values (Basic Safety Level)
Target 4	Design Basis fault sequences	1 mSv for initiating fault frequencies exceeding 1×10^{-3} pa 10 mSv for initiating fault frequencies between 1×10^{-3} and 1×10^{-4} pa 100 mSv for initiating fault frequencies less than 1×10^{-4} pa.
Target 7	Individual risk of death from accidents	1×10^{-4} pa
Target 8	Frequency-dose targets (all accidents)	Effective dose, mSv — Total predicted frequency pa 0.1–1 — 1 1–10 — 1×10^{-1} 10–100 — 1×10^{-2} 100–1000 — 1×10^{-3} > 1000 — 1×10^{-4}
Target 9	Total risk of 100 or more fatalities (immediate or eventual)	1×10^{-5} pa

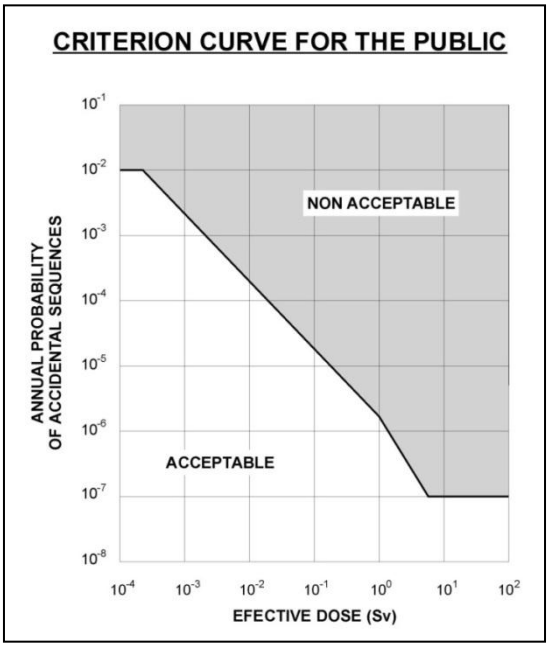

FIG. II-1. Argentine Acceptability Criterion Curve for consideration of potential exposures to the public.

Argentinian Nuclear Regulator

II-28. The Argentine Nuclear Regulatory Authority (ARN) has defined an Acceptability Criterion Curve (a function) against which the nuclear safety level of a nuclear power plant can be assessed [II-12, II-13, II-14] (see Figure II-1 above). The criterion is based on the individual radiological risk limitation quantified in terms of probability and it is related to the dose limitation system recommended by the International Commission on Radiological Protection for protection against normal exposures to ionizing radiation [II-2]. The objective of the Acceptability Criterion is to limit the individual risk to members of the public associated with potential exposures that could originate from living in the proximity of a nuclear facility to values not greater than the individual risk associated with exposures from normal operations.

II-29. ICRP 60 [II-2] has suggested a risk coefficient for stochastic effects of 5×10^{-2} Sv^{-1}. The ARN applies this coefficient to their dose constraint for normal exposure from a single source such as a nuclear power plant of 0.3 mSv per year and derive an annual limit value of the individual risk R, associated with normal exposures originating in a single practice or source of 1.5×10^{-5}.

II-30. For potential exposures the individual risk will be the sum of the risks associated with exposures from all possible accident sequences (a sequence is the series of events leading up to the radioactive release followed by a particular set of meteorological conditions or other exposure pathways that lead to exposure of an individual). The calculated risks do not take account of any counter-measures that might be implemented.

II-31. ARN recognizes that there are many uncertainties involved in probabilistic methods such as Probabilistic Safety Assessment (PSA) and to account for this a lower value (a factor of 15 lower) for the risk limit of 10^{-6} — in other words the individual risk of death from accidents at a nuclear facility for the most exposed individual must be less than 10^{-6} or 1 in a million.

II-32. Figure II-I (above) which is taken from the ARN Regulation [II-13] is a plot of the annual probability of accidental sequences against the effective dose resulting from all accidents with that annual probability showing the criterion curve.

US Nuclear Regulator (to be completed)

II-33. Example of United States Method for Determining Potential Exposures to the Public:

II-34. The U.S. analyses design basis accident radiological consequences against the 10 CFR Part 100 and/or 10 CFR Part 50.67 dose criteria. The base guidance that the NRC provides for facilitating compliance with these criteria is contained in Regulatory Guide 1.195 and/or 1.183, respectively [II-15, II-16, II-17].

French methodology

II-35. An example of assessment methodology for radiological consequences of accidents proposed by a nuclear industry from France, after the request by the regulatory body is presented below [II-18].

II-36. The dose assessments of an accidental release takes into account four pathways from which populations living near the site are subject: external exposure to plume radiation, internal exposure due to inhalation of radioactive substances, ingestion of contaminated foodstuffs and external exposure to radiation from substances deposited on the ground over a maximum period of 50 years, which reflects the persistent contamination of the environment. In addition, and to account for the particular radiosensitivity of a child, a dose assessment is performed for young child of 1 year.

II-37. In general, two periods of time are considered:

(a) The short term associated with the passage of the plume and the possible decision of measures to protect populations (typically hours to days). Two pathways are dominant in this phase: external exposure to plume radiation and internal exposure due to inhalation of radioactive substances. Conventionally, the short-term dose is calculated at 500 m (distance considered as the boundary of the site). For the assessments, atmospheric dispersion is assessed using a deterministic approach, considering standard meteorological conditions and a Gaussian plume dispersion model, and measures to protect populations are not taken into account.
(b) The long-term assessment is a representation of the impact on an average lifetime. In addition to short-term dose, the dose term is mainly due to the internal exposure due to ingestion of contaminated foodstuffs and external exposure to radiation from substances deposited on the ground. Conventionally, the long-term dose is calculated at 2 km (supposed location of the first villages around the plant). The contamination of foodstuffs is assessed by considering dynamic processes involved in transfer to vegetable and animal products from the date of the accident up until the date of consumption of such products. No restriction on food consumption or decontamination of soil is taken into account for these assessments.

II-38. For operating reactors, for the short term assessment (up to 7 days), operating conditions are distinguished by frequency of occurrence:

(a) for incidental situations ($1–10^{-2}$/p.a), as their annual frequency may be relatively high, the assessment is compared to the limits of the normal operation of the plant that relate to annual releases of activity;
(b) for category 3 accidental conditions ($10^{-2}–10^{-4}$/p.a), the assessment is compared to 10 mSv for total effective dose and to 100 mSv for equivalent thyroid dose, which reflects the non-necessity for sheltering;
(c) for category 4 accidental conditions ($10^{-4}–10^{-6}$/p.a), the assessment is compared to 50 mSv for total effective dose (and to 450 mSv for equivalent thyroid dose), which reflects the non-necessity of evacuation;
(d) for the operating conditions of the design extension condition, values for category 4 events are used.

II-39. For long-term phase, the considered value is 1 Sv which is associated with the proposed value for the full life of a worker in the ICRP [II-2].

II-40. The French regulatory body has expressed an overall positive evaluation on these standards while considering that the objective of continuous improvement in the safety level of operating reactors should be included in the assessment of the radiological consequences of accidents.

REFERENCES

[II-1] INTERNATIONAL ATOMIC ENERGY AGENCY, Fundamental Safety Principles, IAEA Safety Standards Series No. SF 1, IAEA, Vienna (2006).

[II-2] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, 1990 Recommendations of the International Commission on Radiological Protection', ICRP 60, Pergamon Press (1991).

[II-3] INTERNATIONAL ATOMIC ENERGY AGENCY, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards, IAEA Safety Standards Series No. GSR Part 3 (Interim Edition), IAEA, Vienna (2011).

[II-4] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Protection from Potential Exposure – A Conceptual Framework, ICRP Publication 64, Pergamon (1992).

[II-5] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, The 2007 Recommendations of the International Commission on Radiological Protection', ICRP Publication 103, Pergamon (2007).

[II-6] INTERNATIONAL ATOMIC ENERGY AGENCY, Terminology used in Nuclear Safety and Radiation Protection, IAEA Safety Glossary, IAEA, Vienna (2007).

[II-7] INTERNATIONAL ATOMIC ENERGY AGENCY, Extension of the principles of radiation protection to sources of potential exposure, Safety Series No. 104, IAEA, Vienna (1990).

[II-8] INTERNATIONAL ATOMIC ENERGY AGENCY, Potential Exposure in Nuclear Safety, A Report by the International Nuclear Safety Advisory Group, INSAG Series No. 9 (INSAG-9), IAEA, Vienna (1995).

[II-9] European Utility Requirements for LWR Nuclear Power Plants, Volume 2 Generic Nuclear Island Requirements, Revision C, April 2001 (available on http://www.europeanutilityrequirements.org/eur.htm).

[II-10] HEALTH AND SAFETY EXECUTIVE, Safety Assessment Principles for Nuclear Facilities' 2006 Edition, Revision 1 (available on http://www.hse.gov.uk/nuclear/saps/index.htm).

[II-11] HEALTH AND SAFETY EXECUTIVE, Numerical targets and legal limits in Safety Assessment Principles for Nuclear Facilities, An explanatory note, December 2006 (available on http://www.hse.gov.uk/nuclear/saps/index.htm).

[II-12] ARGENTINE NUCLEAR REGULATORY AUTHORITY, Specifications on Regulation AR 3.1.3 on "Radiological Criteria Related to Accidents in Nuclear Power Reactors – Revision 2", Buenos Aires (2011) DRAFT.

[II-13] ARGENTINE NUCLEAR REGULATORY AUTHORITY, Regulation AR.3.1.3 "Radiological Criteria Relating to Accidents in Nuclear Power Plants", Revision 2, Buenos Aires, Argentina (2001).

[II-14] ARGENTINE NUCLEAR REGULATORY AUTHORITY, Basic Radiological Safety Standards AR10.1.1. Rev3. Buenos Aires (2003).

[II-15] UNITED STATES NUCLEAR REGULATORY COMMISSION, Title 10, Code of Federal Regulations 10 CFR Part 100 "Nuclear power plants and reactors, Radiation protection, Reporting and recordkeeping requirements", United States, January 2004.

[II-16] UNITED STATES NUCLEAR REGULATORY COMMISSION, Regulatory Guide 1.195: "Methods and assumptions for evaluating radiological consequences of design basis accidents at light-water nuclear power reactors", United States, May 2003.

[II-17] UNITED STATES NUCLEAR REGULATORY COMMISSION, Regulatory Guide 1.183 – Alternative Radiological Source Terms for Evaluating Design Basis Accidents at Nuclear Power Reactors, United States, July 2002.
[II-18] EDF Report – information requested.

CONTRIBUTORS TO DRAFTING AND REVIEW

Brownless, G.	Babcock International Group, United Kingdom
Cabianca, T.	Public Health England, United Kingdom
Cailes, C.	The Environment Agency, United Kingdom
Cartier, F.	Swiss Federal Nuclear Safety Inspectorate, Switzerland
Curti, A.	Autoridad Regulatoria Nuclear, Argentina
Daguse, T.	Electricité de France, France
Deguette, H.	AREVA La Hague, France
Dolinar, G.	Atomic Energy of Canada , Canada
Garnier Laplace, J.	Institut de Radioprotection et de Sûreté Nucléaire, France
Harman, N.	Serco, United Kingdom
Hemidy, P.-Y.	Electricité de France, France
Kliaus, V.	Republican Scientific-Practical Centre of Hygiene, Belarus
Lehmann, K.-H.	Technischer Überwachungsverein Süddeutschland, Germany
Moore, J.	US Nuclear Regulatory Commission, United States of America
Pinak, M.	International Atomic Energy Agency
Proehl, G.	International Atomic Energy Agency
Robinson, C.	United Nations Scientific Committee on the Effects of Atomic Radiation
Rochedo, E.	Comissáo Nacional de Energia Nuclear, Brazil
Saint-Pierre, S.	World Nuclear Association, United Kingdom
Telleria, D.	International Atomic Energy Agency
Vermorel, F.	Electricité de France, France
Vilkamo, O.	Radiation & Nuclear Safety Authority, Finland
Willrodt, C.	Bundesamt für Strahlenschutz, Germany
Yankovich, T.	International Atomic Energy Agency

Technical Meeting

Vienna, Austria: 28 November – 2 December 2011

Consultants Meetings

Chilton, Didcot, United Kingdom: 18–21 June 2007
Vienna, Austria: 17–21 September 2006
Vienna, Austria: 10–12 December 2008
Chilton, Didcot, United Kingdom: 19–21 October 2009
Vienna, Austria: 26–29 April 2010
Vienna, Austria: 11–15 October 2010
Vienna, Austria: 8–12 July 2013